TP 5934 E

HYBRID CELLULAR AIR CUSHION

SKIRT EVALUATION

FINAL REPORT

Prepared for the Transportation Development Centre

Transport Canada
Montreal

October 1984

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by

D.Jones P.Eng.

October 1984

(ce rapport contient un sommaire en français)

The contents of this report reflect the views of the Contractor, and not necessarily the official views or policies of the Transportation Development Centre, Transport Canada.

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17. Abstract

This report describes an experimental evaluation of a multicell air cushion skirt system intended to improve hovercraft performance by providing greater stability. The system features outer cell walls with a greater slope than the classic multicellular skirt.

The Air Trek 140 hovercraft, with HDL segments, was chosen as the reference vehicle against which the new system would be evaluated. Two models were constructed and tested: a 1:5 scale model was used for over-water stability and drag measurements; a 1:3 scale model was tested for over-land dynamic response.

The system showed excellent pitch and roll stability. This improvement eliminates the need for the usual ballast tanks, thereby increasing the hovercraft payload.

Over-water drag of the new system and the reference vehicle were similar. Excessive drag noted in early tests was traced to water scooping, which was corrected by cropping the inner portion of the cells.

Obstacle clearance tests proved the cells to be virtually snag-free.

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17. Resume

Ce rapport décrit une évaluation expérimentale d'un système de jupe à coussin d'air multicellulaire conçu pour améliorer les performances d'un aéroglisseur en augmentant sa stabilité. Le système est caractérisé par une pente de la paroi extérieure plus marquée que sur le système multicellulaire classique.

Le nouveau système a été évalué en se référant à l'aéroglisseur Air Trek 140 équipé de segments HDL. Deux modèles ont été construits et évalués: un à l'échelle 1/5, utilisé pour les essais de stabilité et de traînée sur l'eau; l'autre, à l'échelle 1/4 utilisé pour les essais dynamiques sur terre.

La stabilité en roulis et en tangage du système s'est avérée excellente. Cette amélioration rend inutile les systèmes de ballastage usuels, d'où augmentation de la charge utile de l'aéroglisseur.

Les mesures de traînée sur l'eau du nouveau système et celui du véhicule de référence sont similaires. La traînée excessive notée lors des premiers essais était due à l'écopage, ce qui a été corrigé par l'ajustement des parois internes des cellules.

Les essais sur obstacles ont démontré que les cellules sont peu sujettes aux accrochages.

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Summary

This Company has been conducting long term research into a cellular skirt that would improve the performance of hovercraft. The results were sufficiently encouraging to warrant further development under contract No. 12SD.T8200-2-2538.

Although the program would consider air cushion vehicles in general, the Airtrek type 140, with H D L segments, was chosen as the craft against which the new system would be evaluated. The trials were therefore based on 1/5th and 1/3rd models of the 140, together with tests on the full scale unit.

The main objective was to improve the pitch and roll stability to a point where the traditional ballast system could be removed, with the associated increase in payload and profit. Additional features to be checked were the over water drag, the resistance of the cells to snagging and the ability to service the skirt without lifting the craft.

Several configurations were tested, the one finally selected involved a horse shoe of cells around the front and sides, with conventional segments across the rear. This design was designated the "Hybrid System".

The over water drag of the Hybrid System and the H D L segments were similar, confirming that the installation of the new skirts would not result in an increase in the propulsive power. No correlation was found between the drag of the model and the full scale vehicle.

Obstacle clearance tests proved the cells to be virtually snag free.

Some of the data has already been used to increase the forward speed of the 140 by 20%.

The substantial improvement in the pitch and roll stability will result in the removal of the usual ballast system. The implication to the present commercial operation of the 140 in British Columbia would be to increase the profit by some $80,000.

Modulation of the air entering the various sections of the cushion will further increase the roll stability to five times that available from current skirt designs. Thus the need to carefully position the payload has been eliminated, resulting in a reduction in the loading time, and hence a quicker turn around.

The objectives of the program have been met, within the budget.

Recent market studies have shown a renewed interest in hovercraft in North America. The Airtrek craft are already competitive in both price and performance, but improvements resulting from the installation of the Hybrid System would give them a distinct edge. A broad outline of a program culminating in the certification of a reskirted craft is presented at the end of this report.

Sommaire

Ce rapport rend compte de la recherche à long terme que le contractant a menée sur un système à coussin d'air multicellulaire conçu pour améliorer les performances d'un aéroglisseur. Les résultats obtenus ont été jugés suffisamment intéressants pour justifier la poursuite des travaux, en vertu du nouveau contrat n° 12SD.T8200-2-2538.

Bien que ce programme ait eu à considérer les véhicules à coussin d'air dans leur ensemble, c'est le véhicule Airtrek - type 140 - équipé d'une jupe segmentée H.D.L. (Hovercraft Development Ltd) qui a été choisi pour servir de véhicule témoin lors de l'évaluation du nouveau système. Les essais ont donc été faits à l'aide de maquettes du 140 au 1/5 et au 1/3, et aussi d'une maquette en vraie grandeur.

La recherche a porté surtout sur la stabilité dynamique du véhicule, en tangage et en roulis, dans le but de l'améliorer au point de pouvoir éliminer le système de ballast actuel, et de profiter de l'allégement qui en résulte pour augmenter la charge utile et, partant, la rentabilité du véhicule. Parmi les autres paramètres vérifiés figurent: la traînée hydrodynamique, la résistance des cellules à l'accrochage et la possibilité d'assurer l'entretien sans avoir à soulever le véhicule.

De toutes les configurations essayées, celle qui a été finalement choisie consistait en un ensemble de cellules placées sur trois côtés, l'arrière ayant conservé les segments classiques. Cette configuration a reçu le nom de système hybride.

Il a été constaté que, dans le cas du système hybride, la traînée hydrodynamique est inchangée par rapport à celle du système témoin, confirmant l'hypothèse que les cellules n'exigeraient pas d'amélioration du rendement propulsif. Aucune corrélation n'a pu être trouvée entre la traînée de la maquette à l'échelle et celle du véhicule lui-même.

Les essais de franchissement d'obstacles ont montré que les cellules n'ont pratiquement aucune tendance à accrocher.

Les résultats de la recherche ont déjà permis d'augmenter de 20 p. cent la vitesse en marche avant du 140.

La plus grande stabilité dynamique en tangage et en roulis obtenue permettra d'enlever le système de ballast actuel; pour le véhicule 140 en service payant en Colombie-Britannique, cet avantage pourra se traduire par une augmentation des profits de l'ordre de 80 000$.

Il est possible, en modulant le flux d'air d'alimentation dans diverses sections du coussin, d'augmenter encore par un facteur de 5 la stabilité en roulis obtenue avec la configuration classique. La nécessité d'un positionnement précis de la cargaison étant ainsi éliminée, les temps consacrés au chargement sont donc réduits, réduisant du coup les durées d'escale.

L'objectif de la recherche a dont été atteint à l'intérieur du budget fixé.

D'après les études de marché les plus récentes, d'intéressants débouchés existent pour l'aéroglisseur sur le marché nord-américain. Le système hybride a permis de donner au véhicule Airtrek un net avantage sur la concurrence, bien qu'il fût déjà concurrentiel quant au prix et aux performance. A la fin du présent rapport sont données les grandes lignes d'un programme devant mener à la certification du véhicule équipé de cellules selon la nouvelle configuration.

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1.0 Introduction

A long term cellular skirt development program has been carried out by this Company over the past years to improve hovercraft performance and reduce costs. It has been supported by small, free flight models and half scale sections of large vehicles.

The Hybrid Cellular Skirt System showed considerable merit, but to bring it to a point where it could be considered for a commercial craft would require additional funding from an outside source. An Unsolicited Proposal was submitted to Supply and Services Canada and awarded under Contract No. 12SD.[illegible], The technical monitoring being assigned to the Transport Development Centre of Transport Canada. The Program included the following three phases.

Phase 1
Model tests over land

Phase 2
Model and full scale tests over water.

Phase 3
Tests at the University of Toronto circular track.

The first installation will be a modified type 140, designed by this Company, manufactured by Airtrek Systems Ltd of Chatham, Ontario, and currently in commercial operation in British Columbia.

2.0 Model Tests

2.1 Test Model

The test model is a 1/5th scale of type 140, the general dimensions of which are presented in Table 1. It has been made from exterior grade plywood, bonded with water resistant glue, and with the central hull filled with foam to provide bouyancy. The skirts are fabricated from a 9 oz P.V.C. cloth, style 8-54-61, supplied by Soper's Ltd. of Hamilton.

The air supply package consists of an electric motor driving two 23 cm diameter straight blade fans located on the same shaft. The fan speed can be altered by changing the pulley on the motor shaft. The fan discharge exhausts into a plenum box from which air is ducted by flexible hoses to the four peripheral quadrants and the central cushion.

Table 1

Hovercraft type 140 and model specifications

			Full scale	Model
Hard structure	length	cm	1120	219.9
" "	width	cm	574	113.3
" "	clearance	cm	61	12.2
Empty	weight	kg	3660	29.3
Operational	"	kg	5440	43.5
Overload	"	kg	7240	58.0
Cushion	area (n.D.L.)	m^2	50.2	2.2
Airflow	cruise R.P.M.	m^3/s	28.4	0.5
"	maximum "	m^3/s	22.7	0.4

The overload case has been included to cover special applications, the natural growth of the vehicle, and give a third point from which to interpolate the results.

Details of the test rig and model are provided in Figs 1-3.

2.1.1 Model Weight

The model was weighed by spring balances placed at the mid points on the four sides. The addition of these measurements gave a total value of 25.3 kg. and showed that the center of gravity was over the center of area of the cushion.

A 2.0 kg weight was permanently fixed to the bow and stern to bring the weight up to the desired level of 29.3 kg. Additional weights were added to reach the other loading conditions.

2.1.2. Cushion Areas

The cushion area of the Hybrid System was calculated from the drawings, assuming that the skirts were fully extended, and the model was level with the surface. They were as follows, and gave a 10% increase over the H.L.L. segments.

Location	Area m^2
Left hand side quadrant	0.37
Right " " "	0.37
Front "	0.20
Rear "	0.20
Central cushion	1.06
Total	2.20

2.1.3 Hybrid System Design Pressures

The pitch and roll stability of a cellular skirted A.C.V. is a function of the pressure difference between opposite cells, the magnitude of which depends on the slope of the fan characteristics and the duct pressure losses. In the Hybrid System it is assumed that when the craft is level the static pressure under the vehicle will be uniform, hence the pressure losses between the fan and the cells will be the same as that between the fan and the central cavity.

As the craft changes attitude, the clearance under the hem of the down going side gradually reduces until it finally seals with the surface. During this time the pressure in the cell has risen because the fan operating point is moving up the characteristic, due to the decrease in air flow. The increase in pressure in the down going quadrant will be matched by a reduction in that of the central cavity and the upgoing cells, because the total upward force within the cushion must remain constant for a given weight. Furthermore, the design of the inner walls of the cells will ensure that the pressure in the cavity is never greater than that of the up going quadrant.

It is therefore important that the changes in pressure within the model reflect those of the full scale vehicle.

Reference to type 140 shows that the air flow from each fan is 14.2 m^3/s and the exit area is 0.64m^2. Because there is no diffusion in the cushion the velocity of the exit air is 22.2 m/s. Assuming a velocity head loss due to expansion into the cushion, the discharge total pressure becomes 14.1 cm H_2O to support a cushion pressure of 10.8 cm H_2O, giving a total pressure loss of 30%

Reference to the fan characteristics shows that the pressure in the fan serving the down going side will increase by approximately 20%.

As the cell height reduces in roll, the area will increase due to the angle of the walls, and this, together with the reduced pressure losses as the flow approaches zero, results in a pressure 2.5 times that of the central cavity at the maximum pitch or roll attitude.

2.1.4 Air Flow Distribution

One of the advantages of the Hybrid System is that a large part of the total flow can be ducted directly into the central cavity, thereby reducing the size and complexity of the ducts feeding the various sections.

In the model, consideration was given to proportioning the air flow to represent the percentage of the cushion served by a particular quadrant, which would require 16.5% to the sides, 9.2% to the ends and 49.6% to the center. Unfortunately this could only be accomplished through the installation of orifice plates, which would alter the pressure drop characteristics, and hence the performance.

Six similar measuring sections were therefore fitted into the plenum box, one being ducted to each of the four quadrants, and two directly into the central cavity. This configuration would theoretically provide the correct flow into the sides, but slightly more to the ends, at the expense of a lower flow to the center, Fig 2.

2.2 Model Tests Over a Hard Surface

The first series of tests was carried out to ensure that the air flows and cushion pressures were close to the desired values.

2.2.1 Measured Cushion Pressure

With the craft level at a weight of 43.5 kg and a fan speed of 2200 R.P.M., the cushion pressure across the underside of the model was uniform at 2.0 cm of water, very close to the design value of 1.98. The pressure was measured on a sloping water manometer.

A check was then made of the pressures in the various quadrants with the craft rolled down, with the following results-

Quadrant	Pressure cm of water
Center cavity	1.15
Right hand rolled up	1.15
Left hand rolled down	2.90
Front	1,75
rear	1.75

It can be seen that the pressure in the central cavity is the same as that in the up going quadrant, and those in the end quadrants are close to the value when the craft is level.

The pressure ratio was 2.52, close to the calculated value of 2.5, hence the results obtained from the model will be applicable to the full scale vehicle.

2.2,2 Measured Air Flows

The air flows were measured by recording the mean of four static pressure tappings located in the throats of the standard conical bell mouths, the dimensions for which are presented in Fig4 . Each bell mouth was calibrated in situ by removing the flexible delivery duct from the model and connecting to a standard plate orifice tube, borrowed from the University of Toronto.

The initial results showed that the measuring units were too close together, and the flow into one was effecting that into its neighbour. The two center units were therefore relocated on the blank walls of the plenum chamber and the problem was eliminated.

The following data was taken for a model weight of 43.5 kg and the craft level with the ground.

Intake No.	Quadrant	Air flow m^3/s		
	Fan R.P.M.	2000	2200	2500
1	Rear	.047	.051	.061
2	Right side	.046	.051	.061
3	Center cavity	.053	.058	.065
4	" "	.055	.063	.069
5	Left side	.050	.054	.061
6	Front	.050	.053	.059
	Total	.301	.329	.376

The measured air flow at the fan speed of 2500 R.P.M. is close to the design value of 0.4 m^3/s , attempts to increase the R.P.M. resulted in the electric motor over heating.

The results showed 36% of the flow going into the center cavity, with approximately 16% to each of the four quadrants. Therefore the data for pitch stability may be slightly conservative.

2.3 Snagging Tests

The hard structure clearance under the model, neglecting the skids, was 11.2 cm and to satisfy pragraph 4.3.2 of the Contract the required obstacle was 2.8 cms wide and 5.6 cm high. Rather than move the model over the obstacle it was found to be more convenient to tether the craft and move the simulated gate post.

Passage down the middle of the cells on one side was carried out without difficulty and gave an average resistance of 0.75 kg .

Preliminary tests showed that the outflow of air from the central cushion tended to raise the inner wall of the cell to a point where the obstacle would not make contact. The tests were repeated with the inner wall held down to ensure contact. This proceedure was used for each cell and in 90% of the cases the resistance was less than 0.2 kg . However, in some instances the skirt snagged and a 2.5 cm radius was put on each corner of the top plate before it would pass over the obstacle.

The tests now focused on the post moving from the inside to the outside. The design of the outer wall is similar to that of a conventional segment insofar as the shape is maintained by the material forming a right angle between the bottom of the skirt and the inner attachment point. To pass an obstacle this tie must be broken, or extended, to permit the bottom of the skirt to move outward and upward over the obstacle. The shape of the top plate must not restrict this movement.

A device using a shear pin that can be replaced from the deck has already been successfully tested on the 140 and could easily be incorporated in a hybrid skirt. Four side cells were thus modified, and proved that a shear pin would fail.

The obstacle passing capability was considered to be satisfactory.

2.4 Pitch and Roll Stability

The model attitude was changed by moving the ballast weights in increments towards the edge of the deck. No correction has been made for the vertical C.G. position.

2.4.1 Original Hybrid Design

Before starting these series of tests all the bottoms of the cells were trimmed to be the same distance from the ground.

2.4.1.1. Test Results

The results for the three weights and fan speeds are presented in Figs 5 through 10. The data shows that at the higher weights and lower fan speeds, the traditional characteristic is observed where the attainable C.G. shift rises rapidly as the cell pressure builds up due to the reduced flow under the hem. The maximum value occurs when the cell is sealed with the ground, at which point any further improvements result from the increased cell area as it is depressed.

The overall performance is substantially better than that of the segmented skirt, although in some instances the advantage is reduced by the hysterisis that occurs as the model is returning to the level position.

The results for pitch and roll at the light weights suggest that if the angular movement can be limited, then these adverse effects can be virtually eliminated.

The results for pitch show that there is very little hysterisis, probable due to the fact that the "knee" in the curve is close to the maximum pitch angle limited by ground contact. The major difficulty appears in roll, where a much greater angular movement is possible. This would suggest physically limiting the roll angle, or as can be seen from Fig 6, providing a suitable fan characteristic. However, in no case was the model unable to return to the level position after the rolling moment had been removed.

Although the tests suggested that there is a combination of fan discharge pressure and flow that will overcome the problem, operational conditions could exist where an undulating surface could impose a temporary angle that was greater than the "knee".

This condition was simulated by moving the ballast to the edge of the model and then depressing the remaining distance by hand. The motor was turned off and the model permitted to settle on the ground. The motor was then switched on and a set of data taken.

The results are presented in Fig 11 and show that there is a slight increase in the hysterisis, although the performance is still well above that of the segments.

Unfortunately, time and budget constraints did not allow a detailed investigation of conditions at the "knee", or what fan characteristic would eliminate hysterisis.

However, a pressure survey was taken under the model to determine if this parameter contributed to the difference in roll stability between the fan speeds of 2500 and 2200 R.P.M., at an operstional weight of 43.5 kgs.

At zero roll angle the static pressure was constant across the underneath of the model, and this value remained steady in the end quadrants through the roll. The pressure in the up going cells and the center cushion was also always the same and fell as the roll angle increased, compensating the rise in cell pressure in the down going side.

Since the stability is a function of the difference in pressure between opposite cells, this parameter was plotted against the roll angle for the two higher fan speeds. The results are presented in Fig 12. It can be seen that the pressure differences for the fan speed of 2500 R.P.M. do not show any hysterisis, and that observed in Fig 6 may be due to the stiffness in the skirt material. However, the hysterisis for 2200 R.P.M. of Fig 6 is reflected in the pressure differenes in Fig 12.

2.4.2 Hybrid System - Cropped Cells

During the initial over water trials the inside walls of the front cells had been shortened by 2.0 cms to stop scooping. this modification was now applied to all the cells and the roll stability measured at a model weight of 43.5 Kgs, and a fan speed of 2200 R.P.M.

The results are presented in Fig 13 and show that the steep slope has been reduced and the "knee" of the curve moved out of the normal operating range.

This could be one method of changing the ride to suit an operaters requirements, a feature not available with conventional segmented skirts.

2.4.3 Model Fitted with H.D.L. Segments

A review of published data indicated that it would be difficult to determine the performance of a full scale craft from model information, unless some form of correction factor had been established.

Since the model was 1/5th that of the 140, it followed that if segmented skirts were fitted to the model, then the test results could be compared to those from the 140 and the relationship obtained. The model data from both the skirt systems could also be compared and thus the performance of the 140 with the Hybrid System determined.

The H.D.L. segments were installed without any modifications to the model, confirming that the Hybrid System could be attached without any major rework.

Each segment was fabricated from the same material as that used for the cells. The rear corners and the skirts across the back, all had inside walls and slippers to prevent snagging and scooping. The air distribution system remained unaltered.

2.4.3.1 Test Results

The basic pitch and roll stability was measured and is presented in Fig 14 & 15, the airflows were also checked and found to be 5% below the previous readings. The results for a similar model 136 , but with skirts made from 2.0 mil polyethelene is also included and demonstrates the effect of material stiffness.

2.4.4. Modified Hybrid System

Experience gained on the type 140, together with a clearer understanding of user requirements, suggested that the desired level of improvements in the pitch and roll stability could be achieved by replacing the cells around the aft corners and across the rear of the craft with H.D.L. segments. This would simplify the internal ducting, since air need not be supplied to the rear of the vehicle.

The model was modified and the duct normally feeding the rear quadrant now discharged directly into the center cushion.

2.4.4.1 Test Results

The roll stability was measured for a model weight of 43.5 kg , a fan speed of 2200 R.P.M. and a plenum box pressure of 4.7 cms of water. The results are presented in Fig 16, together with those of the cropped cell from Fig 13., so that the data can be easily compared.

The pitch stability is shown in Fig 17, together with those of the cropped cells and the H,D.L. segments.

The results are discussed in paragraph 4.

2.5 Over Water Trials

Although the Hybrid System has shown substantial improvements in the pitch and roll stability, it must also have a similar, or lower over water drag to the H.D.L. segments in order to be considered as a replacement.

The over water performance of these two concepts will be measured in the towing tank of the National Water Research Institute at Burlington, Ontario. In addition, the drag of the type 140 will be determined so that the relationship between model and full scale can be found. This scale effect will then be used to predict the performance of a commercial craft with cells. Modifications to the Hybrid System will also be tested.

The towing tank was 5 meters wide and 2.7 meters deep, which met the minimum values of 3 meters wide and 2.2 meters deep to avoid wall interference.

The air delivery system was suspended above the model by cantilever beams attached to the carriage, similar to the arrangement used for the tests over a hard surface, shown in Fig 18.

The relatively short length of tank did not permit time to record any pressures and airflows without sophisticated instrumentation, not approved in the budget.

2.5.1 Original Hybrid System

2.5.1.1 Static Stability

The pitch and roll stability characteristics were measured for a model weight of 43.5 kg and three fan speeds. The results are presented in Figs 19 & 20.

2.5.1.2. Drag

Several initial runs were made to check the installation and observe the general behavior of the model. The hump speed was recorded at 2.7 m/s, confirming the theoretical value of 2.8 m/s.

Considerable difficulty was experienced in measuring the drag when the model was being towed from the simulated propeller position, due to the tendency to yaw. A position on the bow was tried and the two results are shown in Fig 21, and since there appeared to be little difference, it was decided to proceed with the program using the forward point. The results for the three weights, with the C.G. over the center of area of the cushion, and at a constant fan speed, are presented in Fig 22. The change of fan speed for a given weight is presented in Fig 23.

The drags were much higher than expected and the trials were therefore stopped until the results had been analysed.

2.5.2 H.D.L. Segments

The initial drags were similar to those of the Hybrid System, and the pronounced stern down attitude suggested that the rear segments were scooping, although they had a trailing slipper attached to the front face of the rear segments.

An apron was installed under the model ahead of the rear section of segments to act as a large slipper that would protect them from the approaching water. The results are shown in Fig 24. The effect of reducing the width of the apron to cover the rear seven segments only is presented also on Fig 24.

The results had suggested that if the nose could be held down the rear segments would not scoop. The apron was removed and the ballast weight gradually moved forward until there was a sudden drop in the drag and the stern down attitude disapperaed. This point was at a forward C.G. position of 1.5%, and the result, together with additional C.G. stations are presented in Fig 25. The effect of weight is Shown in Fig 26.

A basis for comparison with the Hybrid System has now been established, although the drag level was well above that predicted from theoretical considerations.

2.5.3. Modified Hybrid System

Windows had been installed in the front and rear of the model so that the flow under the skirts could be observed when the carriage was moving. The rear skirts were seen to be filling with water, despite the slippers attached to the bottom of each segment. The cause seemed to be water forcing the edges of the slipper into the segment such that the inside walls collapsed and exposed the bottom of the outer wall to the oncoming water, and scooping occurred.

This was resolved by removing the slipper and replacing it with a reverse scoop, which is essenially a slipper with the sides attached to those of the segment.

Observations through the front window showed that the inner walls of the front cells were still scooping, so they were cropped by 4.0 cms. Water was also seen accumulating in the distribution galleries; this problem was overcome by drain holes.

A series of tests were carried out to determine the effect of weight and C.G. position on drag, the results are presented in Fig 27. The high values measured with the C.G. in the most forward position was caused by one of the front three cells still scooping occasionally. However, rather than crop the inner wall still further and thus reduce the pitch stability, the airflow was increased by changing the fan speed from 2200 to 2500 R.P.M.. The results are given in Fig 28.

The hump speed for the Hybrid Sytem appeared to be at a much lower value than previously experienced, the fan speed was reduced to the usual 2200 R.P.M. and a detailed investigation of the hump carried out. The model mass was also increased up to the maximum carriage value of 6.0 m/s . The results are shown in Fig 29.

3.0 Water Drag of Hovercraft Type 140

The trials were carried out on Mitchell's Bay in Southern Ontario. Speeds were calculated from the time taken to travel a specific course and the wave heights and wind velocities were estimated by on board observers.

The craft weight was approximately 5,400 Kgs, and the C.G. position was kept in the neutral position, over the center of area of the cushion.

The correction for the water depth was taken from DINSRDC 81/26 and is presented in Fig 30 .

3.1 Thrust

The drag is assumed to be equal to the net thrust which can be determined from a static thrust calibration and the forward speed. The majority of the tests were carried out using a six bladed propeller, although in the latter stages a five bladed unit was installed. the static thrust calibrations versus engine R.P.M. are presented in Fig 31.

3.2 Drag

The total drag is made up of the aerodynamic, cushion momentum, wave form, wetted and wave impact components. The first three are open to analytical analysis but the last two can only be derived by subtracting the theoretical values from those measured during the tests. The wetted drag must be obtained when the conditions are calm so that the wave impact term can be ignored.

The wave impact drag has been derived by calculating the calm day drag for the test conditions, and subtracting it from the test data.

3.3 Tests Proceedure

In most cases the engine R.P.M. was set, the control vanes fully opened, and the craft speed stabilized before entering the test course. Engine R.P.M., the time to travel the course, the wind and wave conditions were recorded.

A slightly different method was used to determine the hump drag, because it was impossible to stabilize the speed at that particular point. A low engine R.P.M. was selected and the craft kept on course for at least 0.5 km . If the hump speed had not been reached by the end of the track, the proceedure would be repeated until the craft had accelerated through the hump, characterized by a stabilized speed above the theoretical value of 20 km/h .

3.4 Test Results

The test results are presented in Table 2 and show that there are six points where the conditions were sufficiently calm to be used to correlate the model and craft performances.

3.5 Wetted Drag

The theoretical drag for a calm day is presented in Fig32 , together with the test points. If the proceedure outlined above is adopted, and the differences in drag divided by the forward speed squared, then the data can be reduced to the traditional drag coefficient.

The average value for the coefficient was 0.082, and has been used to modify the theoretical performance of Fig32 .

3.6 Wave Impact Drag

The data from Table 2 gave an average wave impact coefficient of 0.01 per centimeter of wave height.

Table 2

Test No.	Wind Speed ft/sec	Wind Direction	Wave Height ft	Engine R.P.M.	Craft Speed ft/sec
Six bladed propeller, C.G. position +0.00%					
1	0	/	0	1500	10
2	5	port aft	0	2100	32
3	5	stb front	0.5	1750	11
4	10	port aft	0.5	2000	12
5	10	stb front	0.75	2000	11
6	10	stb front	0.75	2300	27
7	10	port aft	1.00	2500	34
8	0	/	0	2600	43
Six bladed propeller, C.G. position +1.7%					
9	0	/	0	2200	34
10	0	/	0	2400	47
11	0	/	0	2600	49
Five bladed propeller C.G. position +1.7%					
12	0	/	0	2650	36
13	40	stb front	2.0	2800	20
14	40	port aft	2.0	2800	33
15	40	into wind	2.0	2800	16
16	40	port beam	2.0	2800	30
17	40	port front	2.0	2800	28
18	40	15^0 off wind	2.0	2800	30
19	40	down wind	2.0	2400	40

Note - These last eight points were timed by the O.P.P. radar gun held by an officer seated in the right hand seat.

4.0 Discussion of Results

The aim of the Hybrid System is to provide an operater with a vehicle that is tolerant to the positioning of the cargo and passengers, and will also give a comfortable ride over rough terrain and water.

The object of this particular program is to evaluate the concept by comparing it to conventional H.D.L. segments.

The results of recent studies have shown that the most immediate market lies in the 15 to 60 passenger range. The analysis will therefore be oriented towards that class and will take into account the operational experience already gained on type 140 , currently in commercial service.

Most of the improvement can be achieved through additional pitch and roll stability, providing this does not result in an unacceptable increase in the lift or thrust powers.

4.1 Overland Performance

The pitch and roll characteristics for the original hybrid system, involving cells around the complete periphery of the model, are presented in Figs 5 through 10. They show a substantial improvement in stability, even if the performance is taken as that of the lower curve. The cause of this hysterisis is as yet unknown, but discussions with the U.T.I.A.S. suggest that it may be a function of the skirt material buckling.

The data indicates that the problem can be overcome if the fan characteristics are such that the restoring forces do not permit the craft to pitch or roll beyond the "knee" of the curve. This implies that the pressure differences alone will provide the

returning moment and the additional forces incurred by the cell area increasing as it is depressed are not required.

The ability to change the stiffness by fan speed alone is of importance since it will permit an operater to carry loads that would be outside the normal C.G. range, without installing a system that would compromise the ride.

It can be argued that the same result would come from a B.H.C. bag/finger skirt with inflated center keels. This type has not been considered because of the relative small size of the craft and the difficulty of carrying out repairs without expensive support equipment.

A direct comparison between the two subject skirts can be made by examining Figs 14 and 15. It can be seen that the stability of the cellular system is substantially greater than that of the H.D.L. fingers, for the same weight and fan speed.

Cropping the inner walls of the cells will reduce both the slope of the stability curve and the hysterisis, as can be seen from Fig16 . Unfortunately time permitted only one configuration to be tested and this parameter should be examined further in any future program. A different set of skirts could be supplied for use over land and water, and could be changed with the season, similar to the installation of snow tires at the start of winter. Reference to Fig .17 shows . the cropped cells are still much better than the segments.

The high hydrodynamic drag of the first tank tests of the Hybrid System, suggested that the rear cells may be scooping and would need to be modified to a configuration similar to the rear segments of the H.D.L. installation. However, rather than divert the program into the development of rear cells, a check indicated that sufficient stability would be obtained by installing cells around the front and sides, with closed segments across the rear and aft corners. This would also simplify the internal ducting, with the associated savings in cost and weight.

As expected, the roll characteristic, Fig 16, did not change from that of the cropped cells, since the cells down the sides had not been altered. The pitch, Fig 17, was better than the cells alone in the nose down attitude. There was also an improvement in the nose up attitude when compared to the segments, presumable due to the greater stability of the side cells adjacent to the rear.

In practical terms the aft movement range of the C.G will be reduced. This is not important on the 140 since the payload nearly always brings the C.G. forward, and this will be taken care of by the greater stability margin of the front cells.

The Hybrid Sytem, modified with H.D.L. segments at the rear, will be the configuration adopted for further studies.

4.2 Towing Tank Tests

The towing tank tests were carried out in two parts, the first involved stability, and the second, drag.

4.2.1 Stability

The pitch results of Fig 19 shows that the hysterisis has nearly disappeared, and the performance at the two higher fan speeds is the same. This is not suprising, since once sufficient airflow and pressure have been delivered to the cell to displace the water, any additional flow will vent out under the bottom of the cells without changing the performance.

The results for roll, Fig 20, also shows a much reduced hysterisis, although the reason for any hysterisis is not clear, and can not involve skirt buckling due to ground contact.

In both cases the stability over water is less than that over land, but is still greater than that of the segments.

No stability checks were made for the cropped cells, or the Modified Hybrid System, due to emphasis being placed on the drags.

4.2.2. Drags

Although the general level of drag is important, of prime concern is the value at the hump, since this will be one of the factors used to select the thrust power.

The results of Figs 22 & 23 show much higher drags than expected and scooping of the rear skirts was suspected. Although the results were discouraging, reference to JEFF A & B, using a pericell and bag / skirt system respectively, showed that their drags were comparable. Hence the problem was related to this particular hybrid concept, or the method of estimating the drag did not apply to models of this size.

One of the purposes of this Program was to compare the two skirt systems under review. The model was therefore changed to H.D.L. segments to see if the same high level of drag persisted.

The first run gave a drag of 30 kg at the hump, which was similar to those for the Hybrid System and was accompanied by a stern down attitude indicating rear segment scooping. Fig 24 shows that with the apron installed to mask the rear segments the drag at the hump was reduced to 5.5 kg, confirming scooping. The apron was cut to cover the rear seven segments only and resulted in a hump drag of 6.2 kg. However, the drag for the complele apron became higher than the cut configuration as the forward speed increased indicating that the design of the complete rear assembly required further investigation.

The effect of weight was determined by increasing the model to 57 kg and repeating the test at a C.G. position of +2.6%. Fig 26 shows that the drag is higher, but not by the ratio of the weights squared, as predicted from theory.

The data for the Modified Hybrid System , Fig 27, shows that the effect of a reduction in weight is dramatic, however, the results were masked by the observed scooping of the front cells at 43.5 kg.

The effect of a C.G. shift over the range envisioned for the type 140 does not change the hump drag by any appreciable amount. The effect of a 14% increase in air flow, Fig 28, is not significant at either weight, with the exception when the C.G. is well aft. At this point there is a substantial reduction in the level of hump

drag from 11.2 to 8.0 kg. The minor increase in flow, coupled with the slight nose up attitude, was sufficient to stop scooping and give the lower drags. A further small increase in the cushion airflow may well stop scooping at other C.G. positions.

The detailed drag curves of Fig 29 show that if the front cells can be stopped from scooping, then the performance is very similar to that of the segments.

The drag of the 140 , Fig 32, shows that the test results support the theoretical analysis, as long as they include the "wetted" term derived from full scale results. It would therefore seem that the only difficulty lies in the analysis of data from models.

Dicussions with Mr.Ma from the University of Toronto, suggests that interpolation of model results to full scale is very difficult and there is no published general data. The results have been applied to the N.R.C. document LTR - eng - 122, which gives an approximate relationship between model and full scale as the ratio of the weights cubed. In this instance the model is a 1/5th scale of the 140 and thus the model drag should be only 1.6 kg, well below the measured value.

5.0 1/3 Scale Model

The original Contract called for a Hybrid Skirt System to be fitted to a base that would then be attached to the underside of the U.T.I.A.S. circular track vehicle.

The test program would determine,

a) Pitch and roll stability.
b) Performance over undulating terrain.
c) The ability of the cells to move over obstacles without snagging.

Prior to these trials, and outside this Contract, the circular track model was to be upgraded by installing a new lift system, unfortunately, unforeseen problems have delayed the completion of the modifications.

The Contract has therefore been changed by Ammendment 6, to enable this Company to build a new model and complete the Contract. In fact the new test vehicle is more representative of a conventional hovercraft insofar as it employs two centrifugal fans, rather than the single axial fan of the U of T craft. This permits the pressures in the various quadrants of the cushion to follow those expected in a full scale type 140, and hence the results can be directly applied to the commercial vehicle.

5.1 Model Contruction

The base and skirts for the original U.T.I.A.S. test rig had already been manufactured prior to the Contract changes, hence the latest craft involved making a top structure to support the base and lift pack, and provide representative ducting to the peripheral cells. It was constructed of exterior grade plywood and pine stringers, and

has sufficient depth to provide flotation should over water tests be contemplated in the near future.

The model is 396 cm long by 204 cm wide, which is approximately 1/3 rd scale of the type 140. The Hybrid Skirt System is similar to that of the 1/5 th scale model. described earlier, and consists of a horse shoe of cells around the front and sides, with H.D.L. segments at the rear. Air is supplied to the cells by galleries located down each side and across the front. Further ducts direct air from the fans to the center cushion.

The complete craft is presented in Fig 33, with the cell and duct layout in Fig 34.

The lift pack consists of a Volkswagen engine and two centrifugal fans on loan from the National Research Council, who also supplied fan and bell mouth intake characteristics.

Splitter vanes are located in each fan outlet to proportion the fan discharge between the various sections of the delivery ducts, as can be seen from Fig 35.

5.2 Instrumentation

The system pressures were measured by a bank of water manometers located ahead of the model. The fan speed was recorded by a hand held tachometer.

The airflow into each fan was calculated from the measured bell mouth static pressures and the calibration curves. The distribution into the individual galleries was not recorded due to the absence of any suitable instrumentation position.

The pitch and roll angles were obtained from the heights of the sides of the craft above the floor.

5.3 Centers of Gravity

The longtitudinal and lateral center of gravity were obtained by balancing the craft on knife edges. The results showed that the longtitudinal C.G. was at the mid point, but 14 kg of ballast was required 25 cm from the right hand side to bring the rig level.

The vertical C.G. was estimated from the weight and position of the lift system components, together with that of the plywood hull. The value was found to be 58 cm above the underside of the craft. Because of this relatively high vertical C.G. it must be taken into account when estimating the change in the craft C.G. position during an induced pitch or roll.

5.4 Weight

The weight of the empty craft was 472 kg, but since the ballast weight to correct for lateral C.G. displacement is to be permanent, the basic craft weight increases to 486 kg.

5.5 Cushion Areas

The cushion area of each of the side and corner cells is 0.128 and 0.043 sq.m. respectively, however, the cell areas will increase for those being compressed during pitch or roll.

The following areas apply to the level craft.

Cushion area served by the front gallery	0.73 sq.m.
" " " " right hand "	1.28 "
" " " " left " "	1.28 "
" " " " center cushion "	3.32 "
Total cushion area	6.61 sq.m.

The skirt periphery at the hem line is 853 cm.

5.6 Initial Model Configuration

The previous trials on the 1/5th model had been carried out at a plenum chamber pressure 30% greater than that of the central cushion, to reflect the total head loss between the fan discharge and the cushion obtained from measurements on the type 140. This value has been substantiated from published data on J.E.F.F. "A", where losses up to 45% were recorded. Since the loss contributes to part of the pressure increase in the down going cells during the vehicle attitude change, it follows that the lowest loss will result in the weakest stability. Hence the choice of 30% will give conservative characteristics.

These series of tests were therefore conducted by setting the engine speed to give this value when the craft was level, and the splitter vanes in the vertical position. The engine throttle was not changed during a particular run and the fan operating point moved along the characteristic curve during pitch or roll. The engine speed in fact remained constant over all the runs, indicating that the total power absorbed by the fans was unchanged.

Because the shape of the fan characteristics for the model and type 140 are similar, it was assumed that the position of the splitter vanes on the model would have the same effect on the performance of the full scale craft. With the control vanes in the vertical position the air flow into the various galleries was estimated to be,

Left Hand Fan		Right Hand Fan	
Center cushion	67%	Center cushion	48.6%
Side gallery	33%	Side gallery	33.0%
		Front "	18.4%

5.7 Level Performance

The performance with the craft level was obtained to check the instrumentation and the general behavior of the craft. In anticipation of the following pitch and roll stability checks, 26 kg of ballast was positioned on the front and rear, bringing the gross weight up to 538 kg. The cell pressures refer to those at the mid points of the front and sides.

Pressure	Center	Right side		Left side		Front	
		Duct	Cell	Duct	Cell	Duct	Cell
cm H_2O	7.6	7.8	7.7	7.8	7.7	8.2	8.0
Cushion area	3.5		1.28		1.28		.73
Lift kg	266		96		96		57

The summation of the lift under each section of cushion gives a total value of 515 kg, which is close to the measured weight of 538 kg. and indicates that the measured cell pressures and estimated cell areas are correct.

It can be seen that, unlike the small model, the cell pressure in the front is slightly higher than that of the center. This was due to a small uneveness in the concrete floor resulting in a lower hover gap at the front.

5.8 Pitch Stability

5.8.1 C.G. Shift

The pitch stability characteristic was obtained by moving the ballast weights from one end to the other in increments, and determining the corresponding change in angle by measuring the height of the bow and stern.

The results are presented, together with those for the small rig, on Fig 36

It can be seen that the two sets of data are very similar, but there is no hysterysis apparent on the larger unit. This may be due to the fact that the same material has been used in the manufacture of both skirt systems. The effect of material stiffness will be greater in the smaller model, since it would make a bigger contribution to the overall forces acting on the cells.

5.8.2 System Pressures

The individual cell pressure results from that of the delivery gallery and the losses in the connecting duct work, which are a function of geometry and air flow. The data for the vehicle level condition, presented in paragraph 6.6, shows these values to be small, and therefore the individual cell pressures will not be recorded for each of the small changes in attitude required to make up a complete characteristic.

The pressures in the delivery galleries, the center cushion and the fan discharges will be measured for each data point.

As the rig pitches down the front cells seal with the ground, together with the forward cells on both sides. In addition, and because the weight of the craft remains unchanged, the center cushion pressure must decrease to compensate for the increased cell pressure, and area, as the cells are compressed.

The results are presented in Fig 37.

All the cell pressures were recorded at the pitch angle of 3.0° and are presented in Fig 38. At this point the stern had risen 6.5 cm and the bow had dropped 14 cm. As can be seen, the pressure is lowest in the rearmost cell and increases towards the front, until it reaches that of the gallery in the four front cells, which are sealed with the ground.

5.9 Roll Stability

5.9.1 C.G. Shift

The method used to obtain the performance during roll was the same as that for pitch. The results are presented in Fig 40.

The results are very similar to those of the small model, although there does seem to be a fading which increases with increasing roll angle.

5.9.2 System Pressures

The data is presented in Fig 41 and shows the expected trends. In this case the right hand delivery gallery pressure does increase as the flow decreases. The left hand gallery and center cushion pressures are virtually identical, indicating that there is no differential across the inside wall of the cell.

The individual cell pressures across the front were recorded at a roll angle of 5.0°, and are presented in Fig 42.

5.9.3 Fan Air Flows

The fan flows are presented in Fig 43 and show that the discharge from the left hand fan is relatively constant with roll angle, whereas that of the right hand drops as the cells seal with the ground and all the flow is exhausted into the center cushion. This is reflected by the increase in fan outlet pressure, shown in Fig 41.

5.10 Roll Stability - Center Cushion Duct Shut

With a multi fan installation it is possible to divert the flow of the fan serving the down going side so that a greater percentage of the fan discharge is ducted into the delivery gallery. Thus the pressure will rise more rapidly as the flow is reduced with the decreasing hover gap and result in a greater restoring moment.

The splitter vane in the feft hand fan outlet was moved to direct all the air flow into the delivery gallery, and the roll tests repeated. The results are alsc presented in Fig 40 and show a substantial increase in stability. Although the degree of the increase will depend upon the particular fan characteristic, the data clearly shows that a powerful addidition to roll stability can be provided through management of the cushion air supply.

5.11 Performance at Increased Weight

The pitch and roll stability tests were repeated at an increased weight of 665 kg. The results are presented in Fig 44 & 45 and show that there is little change with the previous data.

6.0 Thecretical Performance

The stability is derived from the differential pressure between opposite cells, together with small changes in cell area as the vehicle pitches and rolls. If these are the only forces present, then it should be possible to calculate the stability for any craft from the fan characteristics, duct losses and cell geometry.

6.1 Pitch Stability

A single point at an attitude of 3.0° has been analysed using estimated cushion and cell areas, and the pressures from Fig 38. As a check, the upward forces, consisting of the pressure times area of the individual cells and cushion were calculated and came within 5% of the measured weight. It was therefore assumed that the estimated cushion areas were sufficiently accurate for this analysis.

The estimated C.G. shift was 10% which compared well with the small rig data of Fig 16, but was greater than the large rig shown in Figs 36 & 44., suggesting that there were forces acting on the

large unit that were not apparent on the small model. Examination of Fig 36 shows that the difference increases with pitch angle and may be related to vehicle attitude.

One of the major differences between the two models is the position and speed of the air entering the center cushion. In the case of the small unit there is a large, low velocity, duct located at either end, whereas thelarge rig has two relatively high speed outlets close to the front. This could cause a low pressure area under the front of the hull which would diminish towards the rear through the diffuser effect of the higher rear end. Thus the overall pressure gradient could provide the correct upward force, but with a nose down moment.

Correct positioning of the outlets should permit the theoretical performance to be reached.

6.2 Roll Stability

The same proceedured, together with the data from Fig 41, was used to predict the theoretical performance. Hovever, in this case, the cell pressure in the down going cells was assumed to be that of the delivery gallery, and that of the opposite side equal to the center cushion pressure. Using this technique the theoretical performance could be established across the complete range of roll angles.

The upward force was calculated at each point and found to be 5% lower than the measure weight, with a scatter of 2%. The data was therefore considered suitable for analysis.

The results are presented in Fig 46, together with the measured values from Fig 40. It can be seen that there is very little difference, and the roll stability can be predicted analytically.

7.0 Field Trials

The model was moved to an area where tests could be carried out at speed over a ramp and obstacle of at least 11 cm in height, corresponding to half the structural clearance specified by the Contract. An eight mm movie was taken of some of the tests.

7.1 Obstacle Passing

A 5.0 cm square wooden stake was driven into the ground to a height of 11 cm. Several runs were made with the stake moving under the center and down the sides of the craft. No problems were encountered with the cells, although one of the H.D.L. segments snagged and broke the restraining strap.

7.2 Ramp Tests

A plywood ramp 122 cm long and 14 cm high at one end was installed across a hard packed gravel road so that the towing vehicle could reach a reasonable speed, and there was room for the model to stop.

The speed was calculated from the film, taken at 24 frames a second, and the number of frames for the 3.96 m model to pass a particular point.

Two towing configurations were used, for the first the line was attached to the bow to simulate a towed raft, in the second the line was secured to a high point on the engine frame to represent the thrust line of a self propelled vehicle.

7.2.1 Towed Raft Configuration

The model was towed over the ramp at 2.0 and 4.0 m/s. The visual observations, supported by the film, showed that there was no measurable vertical movement of the deck as the craft went over the ramp, or on the bow after it had passed across the ramp.

7.2.2 Self Propelled Configuration

The same proceedured was used and forward speeds of up to 5.4 m/s recorded. The results were similar to the towed raft configuration, with little vertical movement of the deck as the model went over the ramp.

The effect of changing the forward C.G. position was determined by placing a 100 kg man 76 cm from the bow, resulting in a C.G. shift of 5%. The change in the bow angle was 1.6 degrees and the unit moved over the ramp without any difficulty. The test indicated that the improved stability with the cells did not deminish with forward speed.

7.3 Static Stability

Two of the previous static test points were checked to determine if the rough gravel surface affected the performance. In the first instance a 100 kg man was positioned on the deck as close to the edge of the side as possible. The resulting change in the C.G. position was 8.7%, for a roll angle of 4.0^{o}. This was better than the previous data from Fig 45, due to a small increase in the engine R.P.M.

The second test involved placing three men of approximately 390 kg on the side and changing the position of the splitter vane so that all the discharge from the fan on that side went into the gallery. The resulting C.G. shift was 18.7%, for a roll angle of 3.3^{o}. This again is better than the previous performance and is due to the increased engine speed.

8.0 The Modified Hybrid System fitted to the 140

The immediate market for a hovercraft is in the 1.5 to 5.0 tonne class for use over existing, or proposed, routes that can also be serviced by boats. The current operation in Quatsino Sound is a typical example, where loggers and equipment are moved by crew boats over distances of 30 km at speeds of 45 km/h.

The slightly higher speed of the 140 would probably not be sufficient to warrant a change in vehicle, but the ability to travel over floating debris, the much smoother ride in rough water, and the capability to drop passengers or goods anywhere along the shore line, makes the hovercraft an attractive alternative. Transfering freight direct from a truck to the craft, as opposed to loading a boat over the side of a dock, also seems to be of importance in this particular locale.

The need for a hovercraft has been established and the comparison between the two skirt systems can be carried out using an existing vehicle in commercial operation.

The new skirt system will reduce the initial cost of the 140 by approximately 3% through the elimination of the ballast system, the reduction in the skirt material and lower labour costs. These savings, by themselves, are not large and any advantage for the Hybrid System must come from a reduction in operating costs, an increase in payload for a given vehicle gross weight, and a craft that may be less critical to the position of the payload.

The operating costs involve fuel, skirt repair, general maintainance, saleries etc. The model results showed that the drag of the two systems in the cruise speed range were very similar, hence the required thrust power, and fuel flow would be the same.

The water in Quatsino Sound is usually very calm and the only contact between a segment and the surface is that required to provide stability.

Inspection of the 140 indicated that the light weight segments, made from 16 oz material, would need replacing after 400 hrs, at an installed cost of $5,000. The 40 oz material would last much longer, but the weight penalty would be prohibitive.

The Hybrid System relies on a pressure difference between cells to provide the stability, and since there is no contact with the surface the wear should be much less. In the case of the Modified Hybrid System the wear on the rear segments will be the same as that for the present craft.

If the cells are assumed to have a life three times that of the segments, then the replacements cost per year will be $11,000, as compared to $25,000 for the present craft, resulting in a saving of $14,000.

The 140 has now accumulated over 300 flight hours, and a considerable amount of operating data has been obtained, especially with regard to the weight and position of ballast.

The craft will not accelerate through hump with one pilot, no payload and full fuel tanks, unless there is at least 100 kg of ballast in the nose. When the propeller thrust is taken into account the total applied moment corresponds to a C.G. position of 1.55% forward, which is very close to the 1.5% obtained from the towing tank. This would indicate that the model results for the Modified Hybrid System can also be directly applied to the full scale vehicle. The ballast must be increased to 150 kg to enable the craft to go through hump in a moderate head wind.

The onset of plow in has been encountered on a number of occasions, especially when the craft is empty and there is a tail wind. The 100 kg ballast moved from the bow to the stern is only marginally satisfactory and the weight must be increased to 200 kg to take into account the possible variations in the weight and C.G. position of the payload. The corresponding model C.G. position is -2.0%.

The change in C.G. position while the craft is moving has to date been carried out by crew members moving weights within the cabin. This is not acceptable for a commercial operation and some form of liquid ballast transfere system must be installed. The total weight is estimated to be 250 kg. Unfortunately this must be deducted from the maximum payload since the vehicle is certified for a gross weight, and there are no immediate plans to increase this value.

Now that the minimum fore and aft positions of the C.G. have been establish, the model data can be examined to determine if the Modified Hybrid System can meet the requirements. The test results show that stability can be provided between +2.6% and -3.4%, which adequately covers the full scale range.

Analysis of the operation at Quatsino indicates that the 140 will be running close to the maximum gross weight for the majority of the time, with 300 kg of fuel leaving 1580 kg of payload, which must now be reduced to 1330 kg because of the ballast system. The average tariff for frieght is 25 cents/kg and the schedule calls for six trips a day, six days a week and fifty two weeks a year. Thus the yearly gain from the Modified Hybrid System could be as high as $60,000, assuming that the craft is weight limited for half the journeys.

The 15% reduction in skirt weight, coupled with the saving in fuel due to the 13% increase in the cushion area, result in a further gain of $5,000. per annum.

The total increase in profit substituting the Modified Hybrid System for the present H.D.L. segments becomes $79,000. per year.

Some of the data obtained from the towing tank tests has already been applied to the type 140 in the design of an apron to protect the rear segments. It has resulted in a measured increase in speed of 8 K.P.H.

The substantial improvement in roll stability will permit the full payload to be carried outside the cabin on one side. This will double the load that can now be stowed in this position since no counter balance is required.

9.0 Proposed Development Program

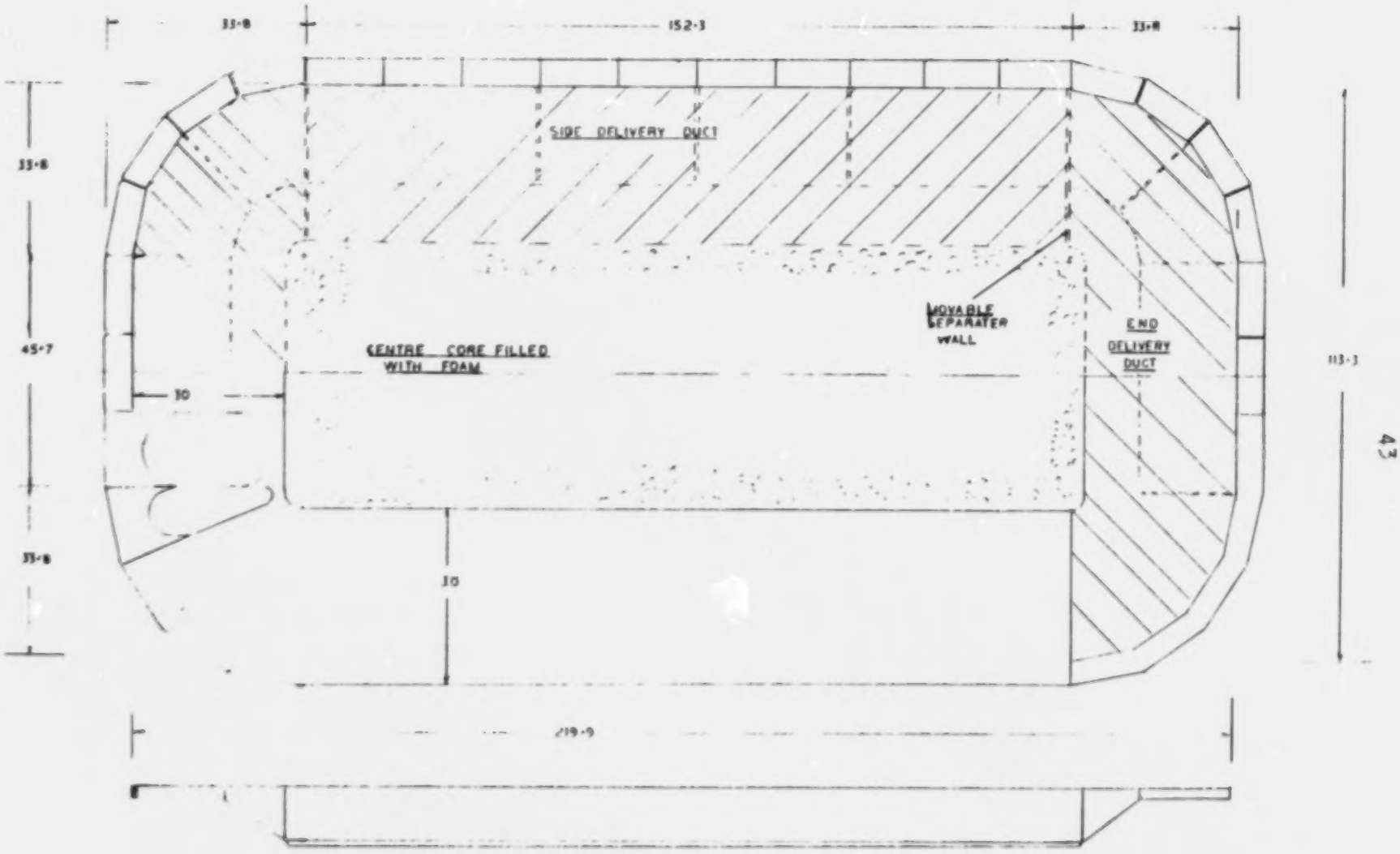
The results of this Contract clearly show the potential of the Hybrid Cellular Skirt System to improve the performance and give a competative edge over craft using existing designs. However, further trials are required before it could be considered for a commercial vehicle.

The first step is to determine the characterisics of full scale cells over water, with particular reference to scooping, plow in and any tendency to buckle under wave impact. To obtain this data it is proposed that the present seven front segments on the type 140 be replaced by three cells and tested under various craft attitudes wave heights and forward speeds.

Upon the successful conclusion of the first phase, the 1/3rd scale model will be used to optimize the cell configuration and confirm the performance over land and water.

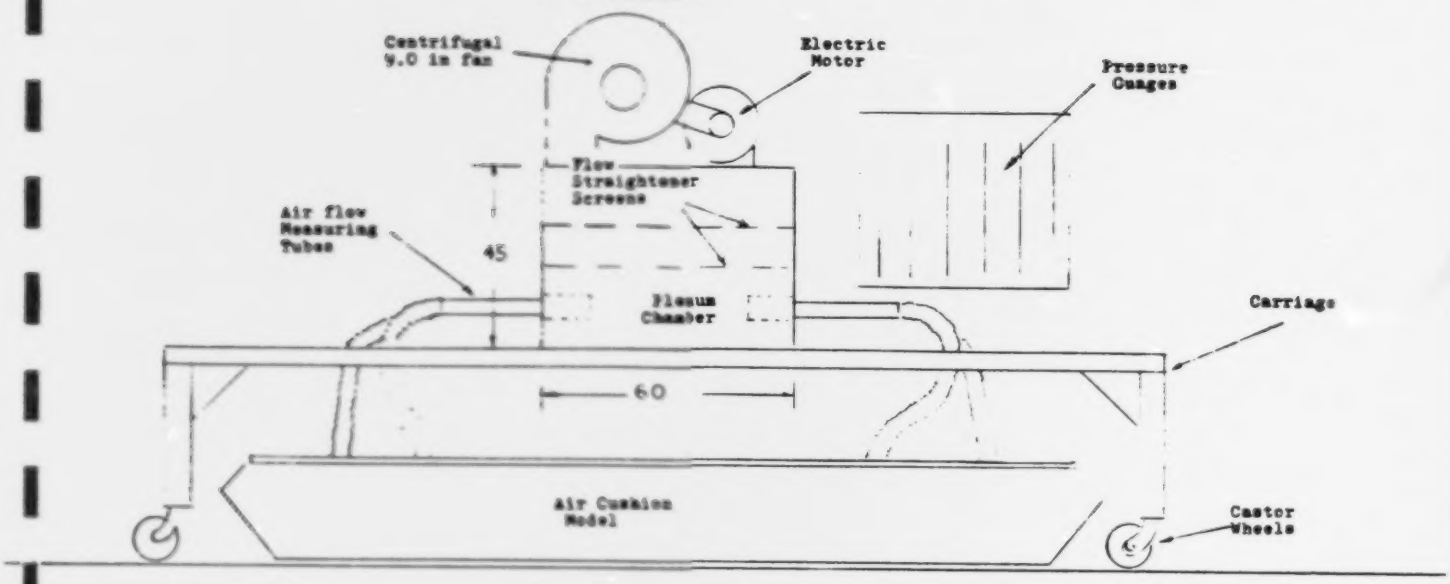
The final design will be checked on the front of the 140 and if acceptable, the complete craft will be modified and a program initiated that will lead to Certification by the Canadian Coast Guard.

The Hybrid System has been discussed at length with Airtrek Ltd., the manufacturers of the type 140. They have expressed the intent not to sell the present first unit but return it to Chatham and use it for product development.



CENTRE HULL
FIG 1

HYBRID CELLULAR SKIRT TEST RIG



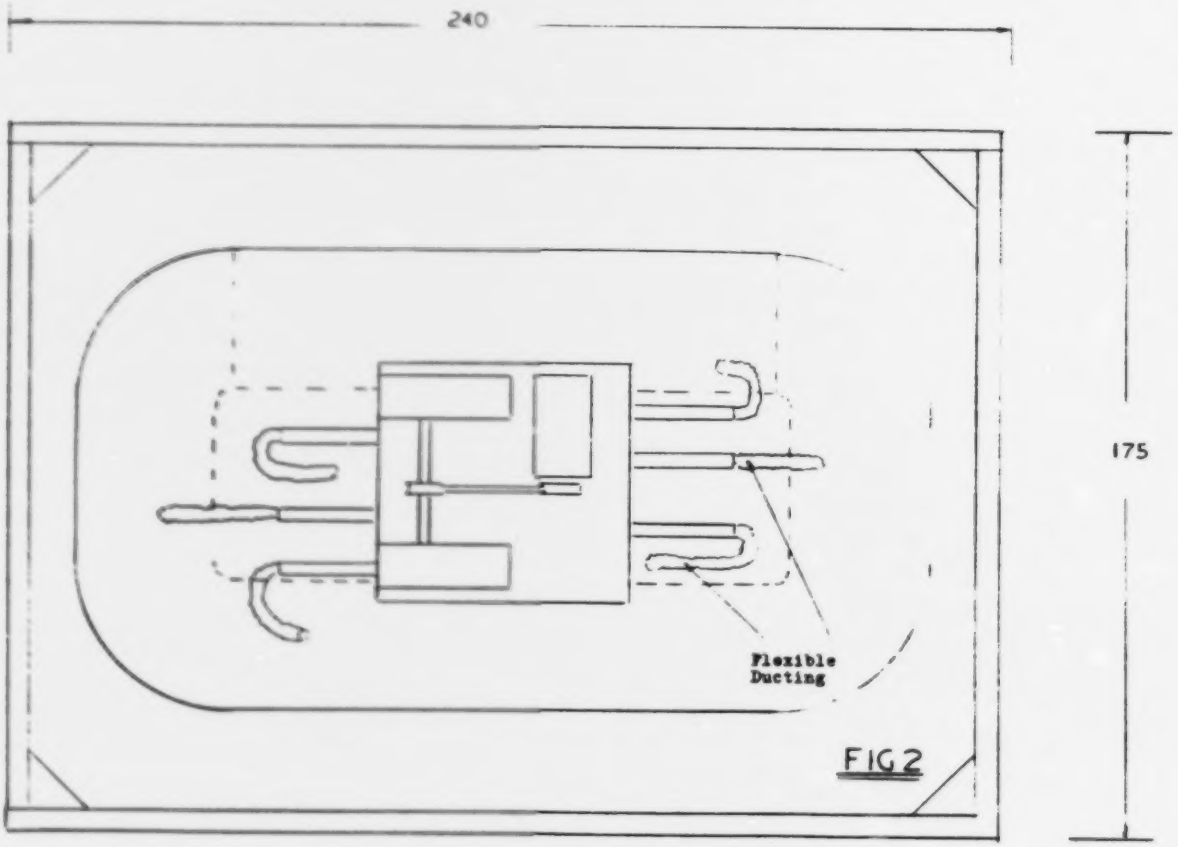


FIG 2

CELL DIMENSIONS

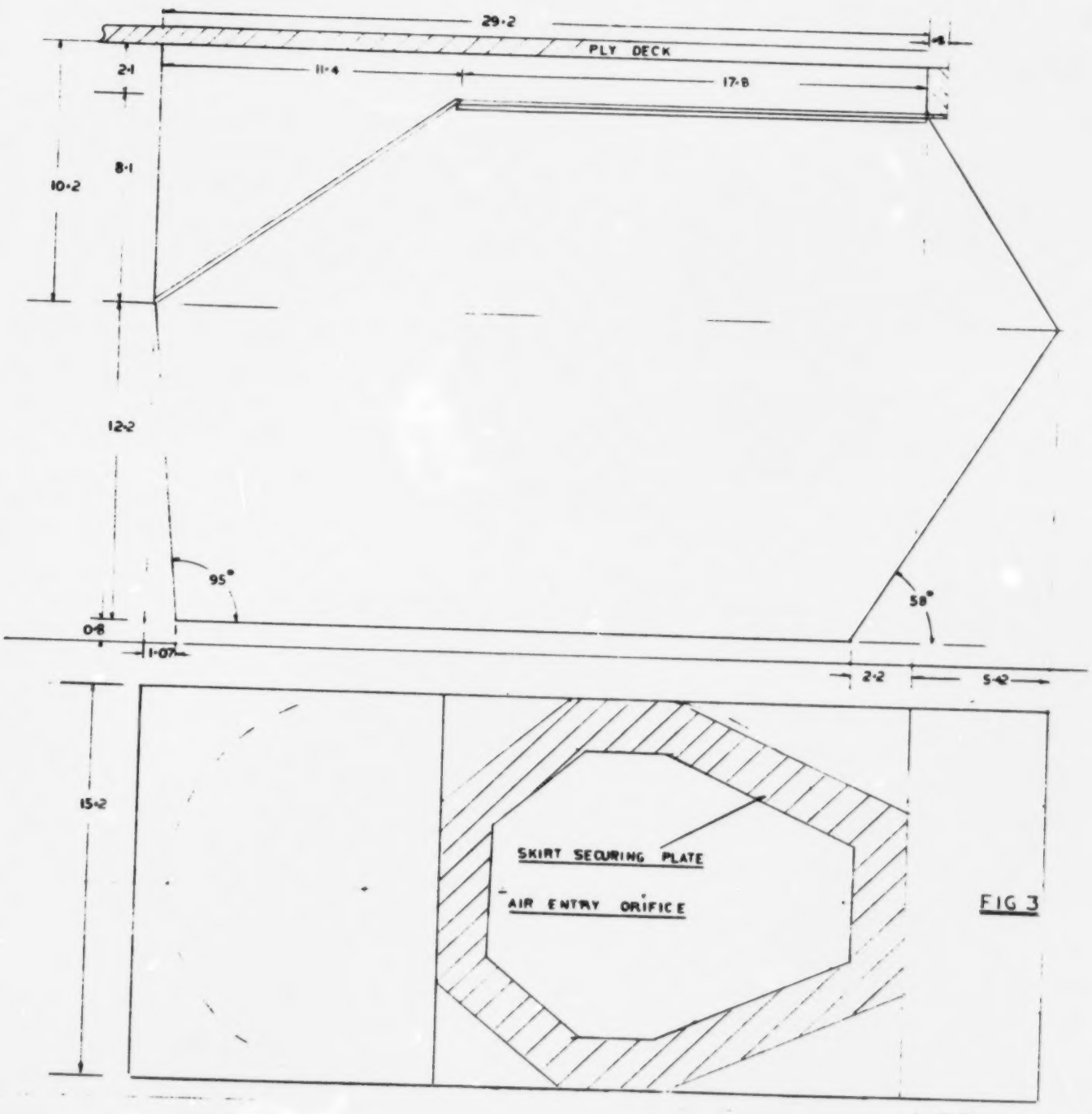
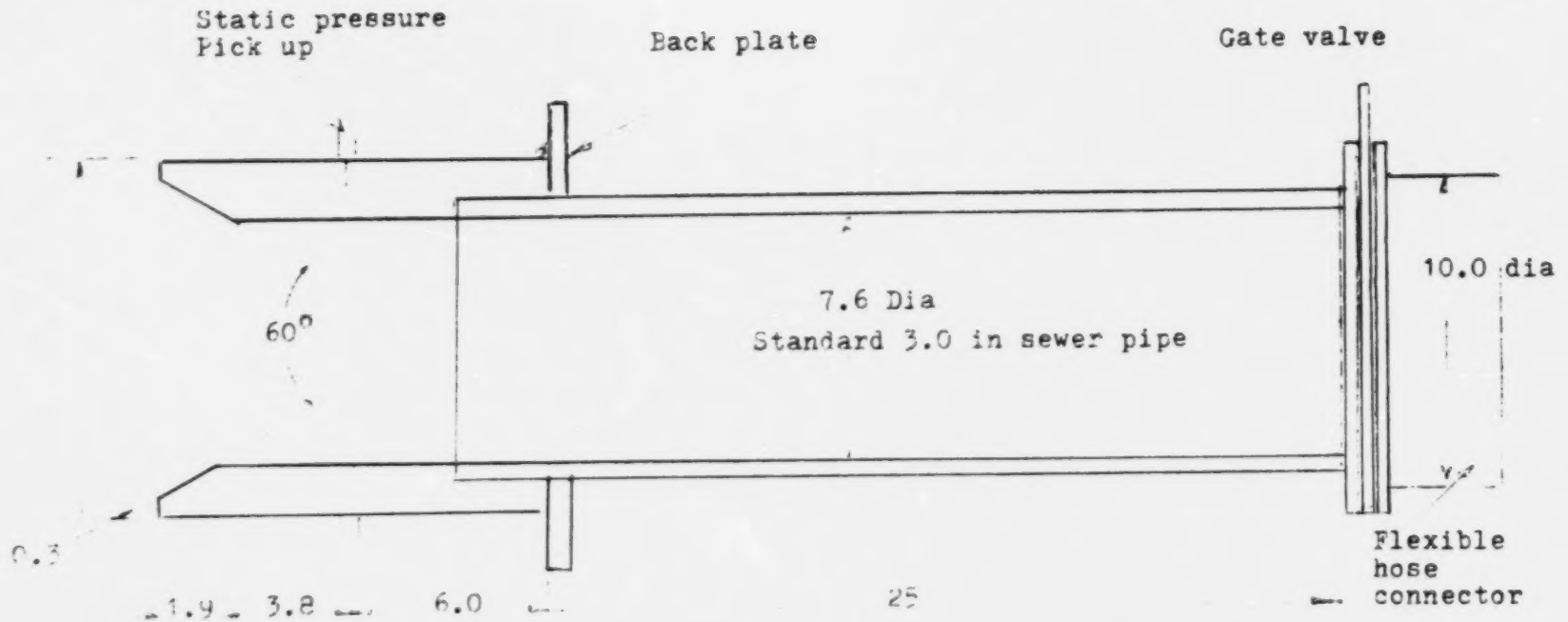


FIG 3

Air Flow Measuring Tube



Machined Aluminium block

Fig 4

ROLL STABILITY

MODEL WEIGHT = 29.3 kg

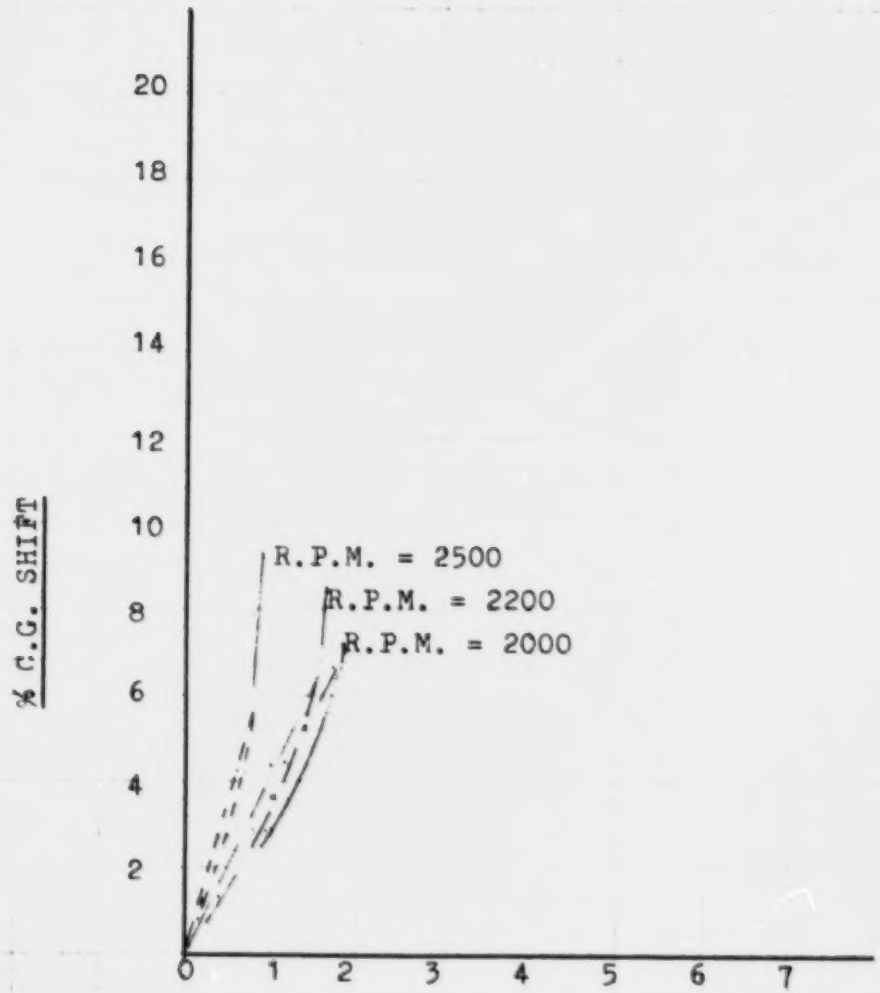


Fig 5

10 Squares to the Inch

ROLL STABILITY

MODEL WEIGHT = 43.5 kg

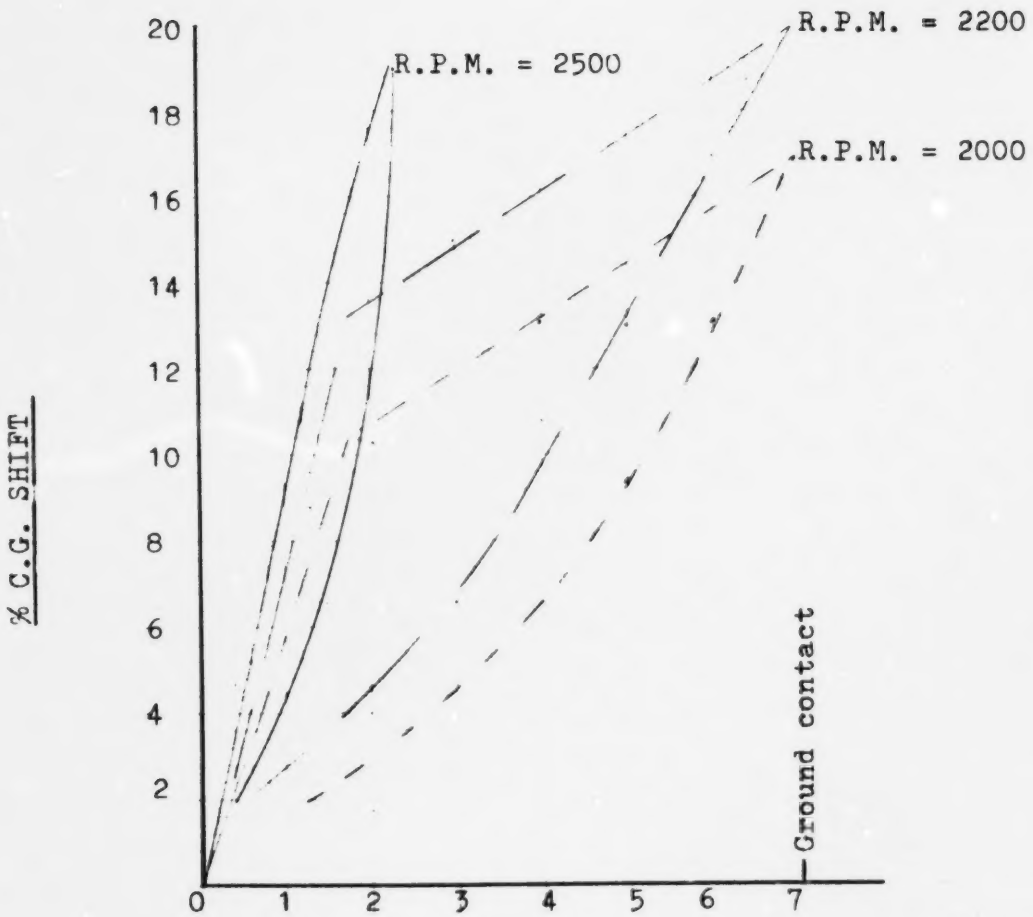


Fig 6

ROLL STABILITY

MODEL WEIGHT = 58 kg

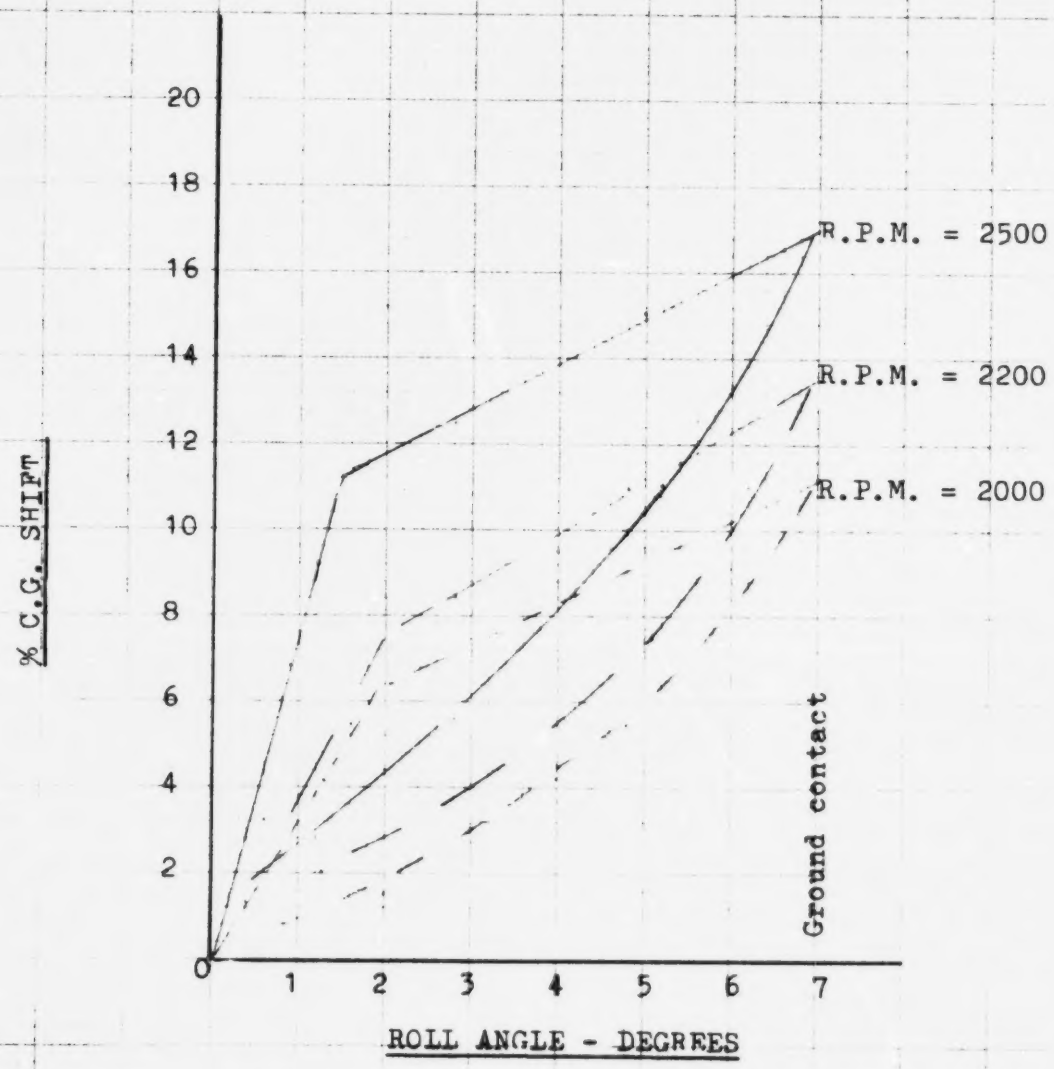


Fig 7

PITCH STABILITY

MODEL WEIGHT = 29.3 kg

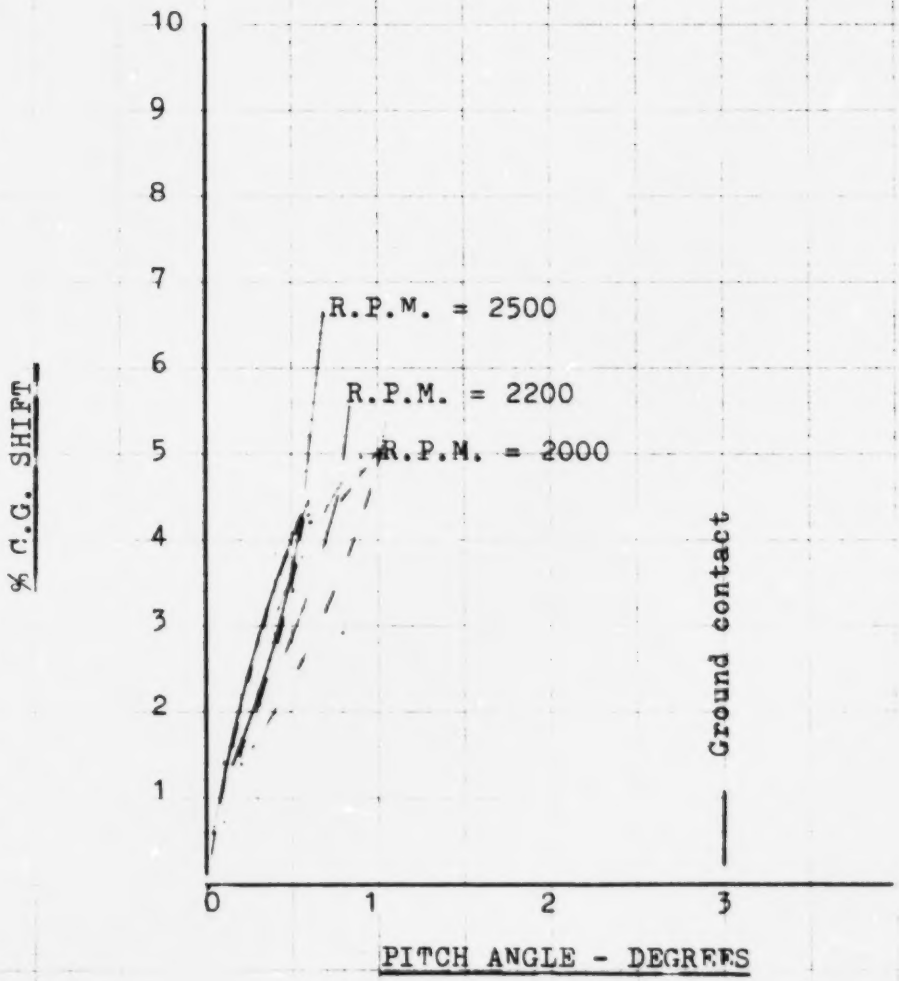


Fig 8

PITCH STABILITY

MODEL WEIGHT = 43.5 kg

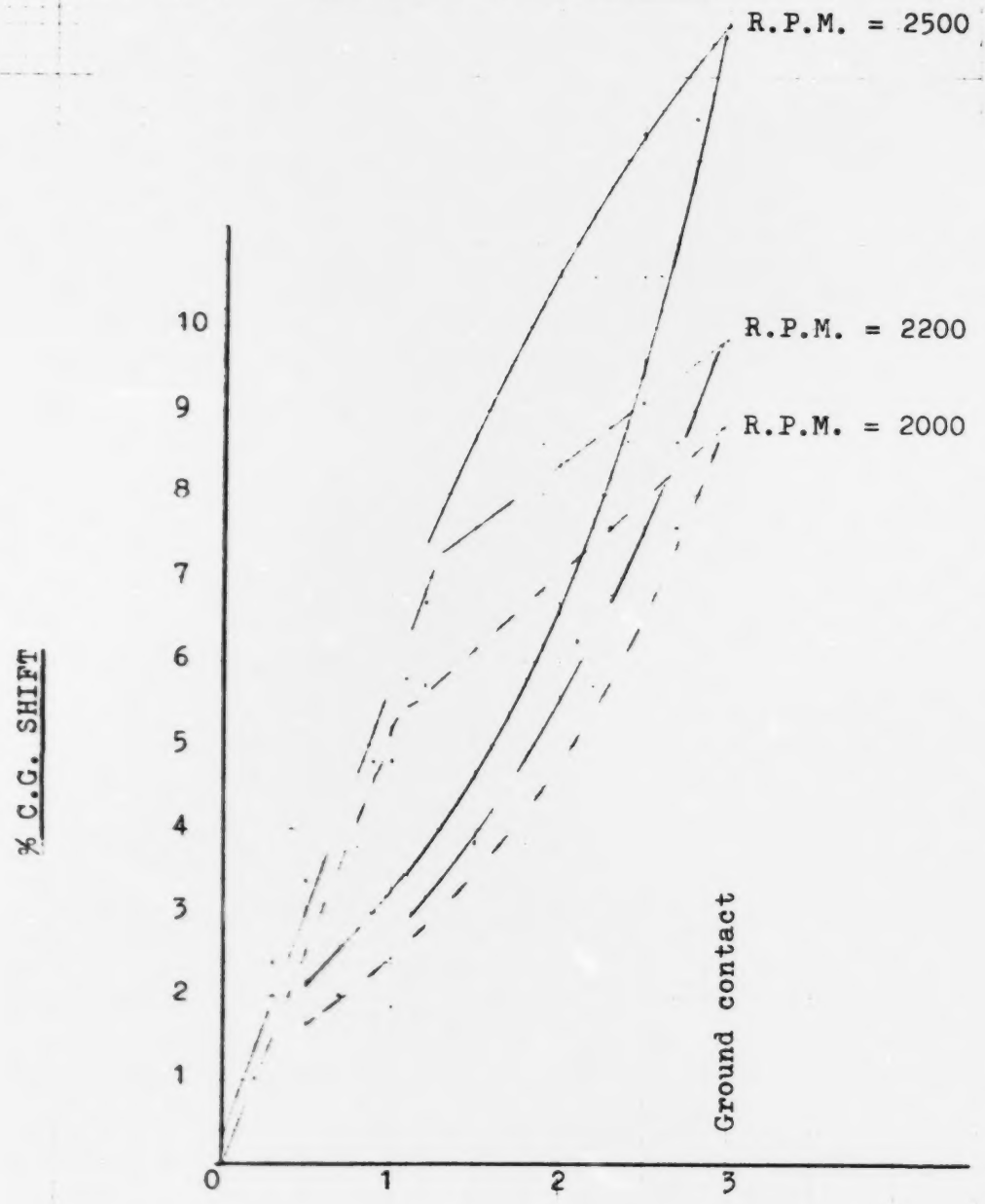


Fig 9

PITCH STABILITY

MODEL WEIGHT = 58 kg

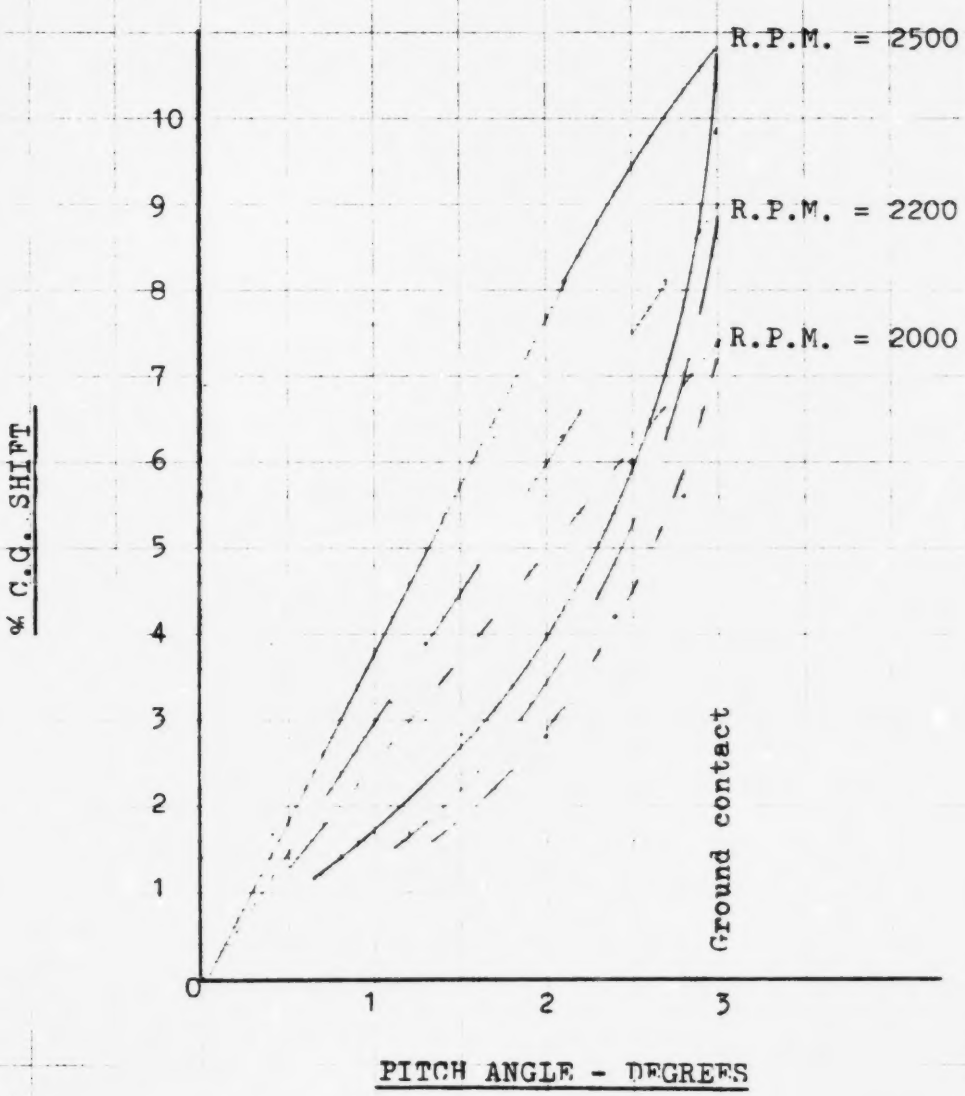


Fig 10

ROLL STABILITY (Repeat)

MODEL WEIGHT = 43.5 kg

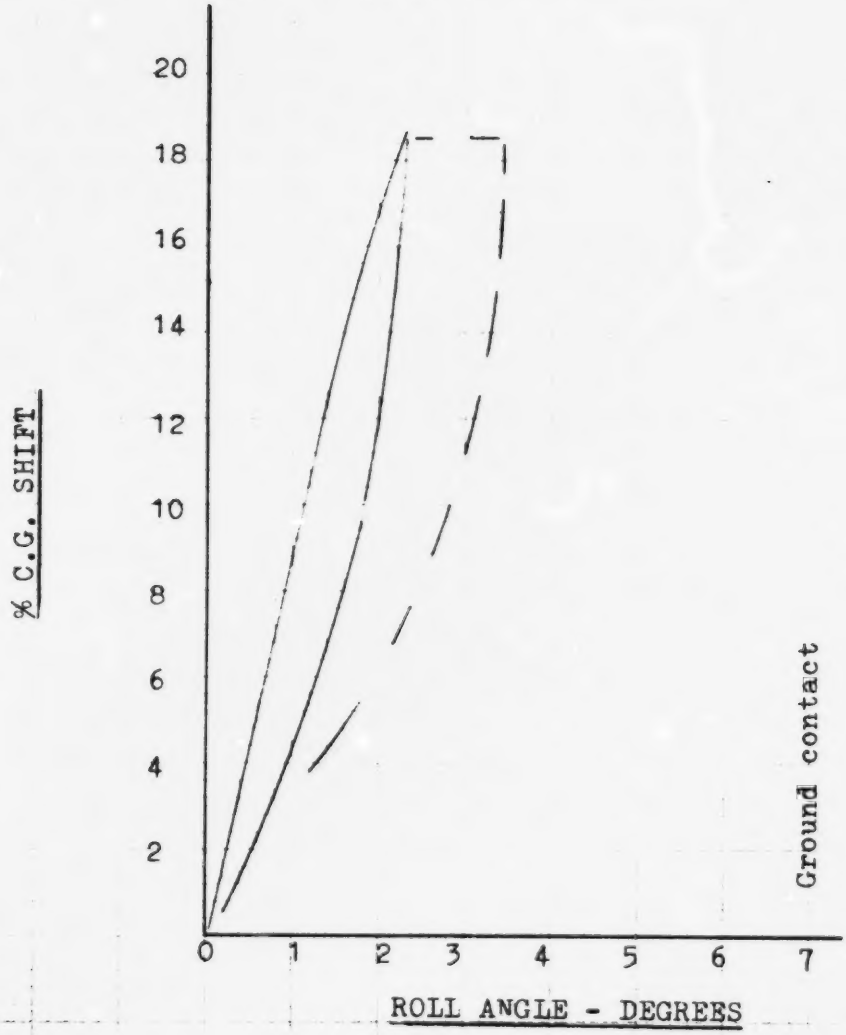


Fig 11

10 Squares to the Inch

CELL DIFFERENTIAL PRESSURE

MODEL WEIGHT = 43.5 kg

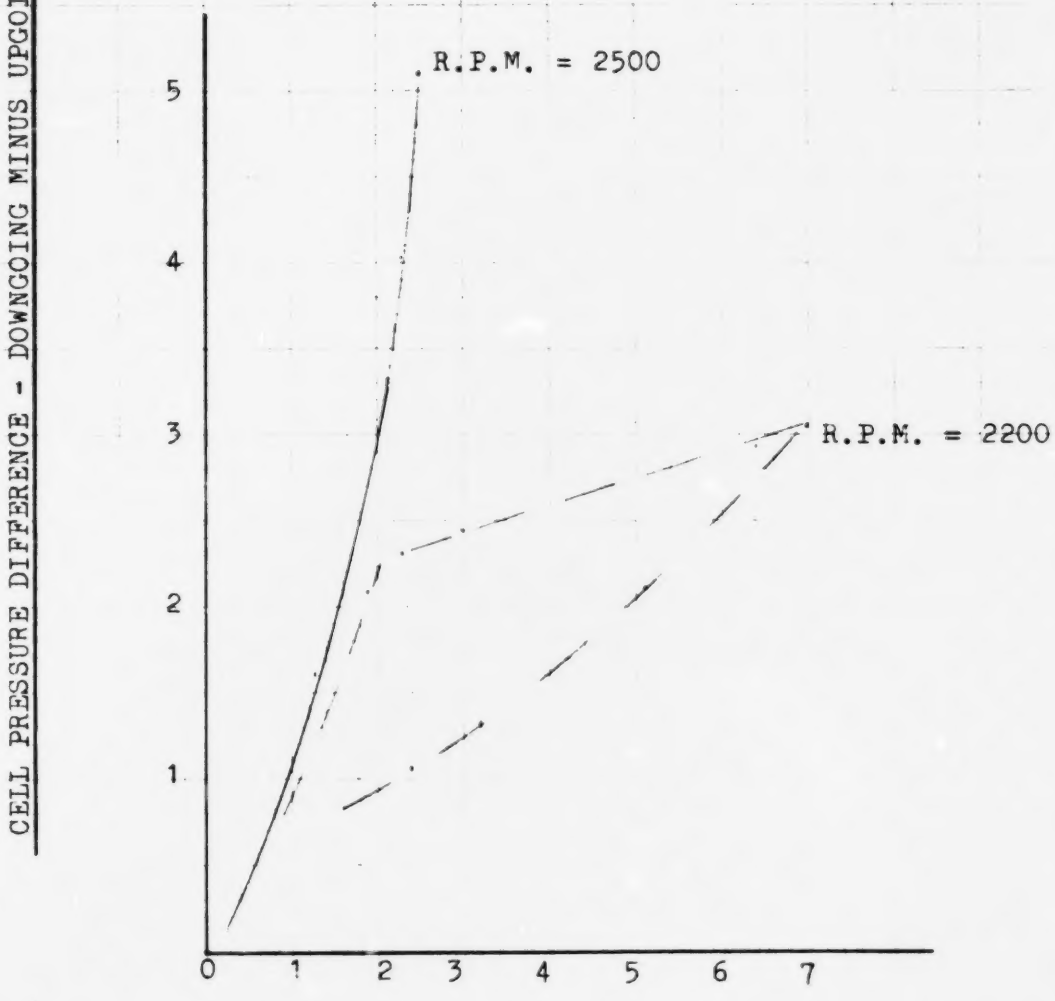


Fig 12

Model type 140 with Cropped Hybrid System
Weight = 43.5 kg.
Fan R.P.M. = 2200

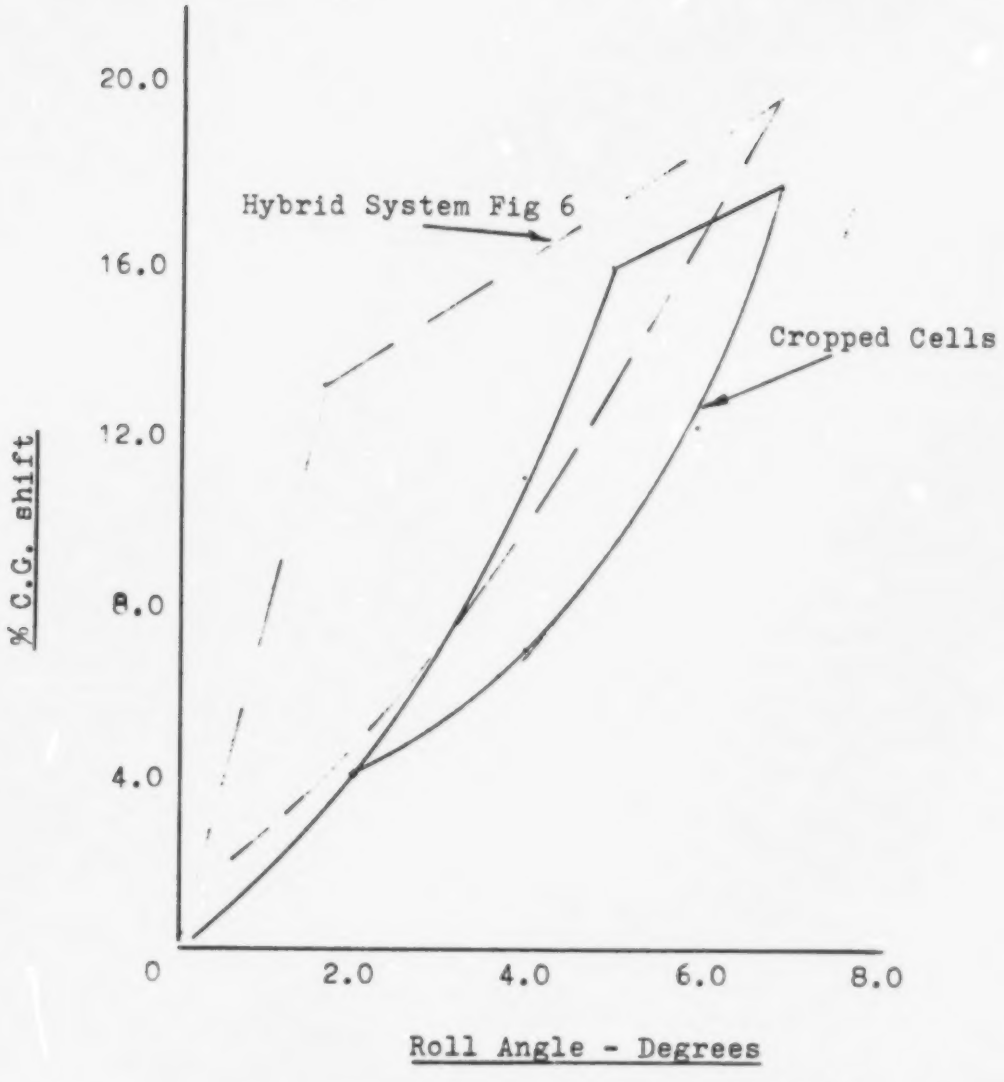


Fig 13

Type 140 Model with H.D.L. Segments
Weight = 43.5 kg
Fan R.P.M. = 2200

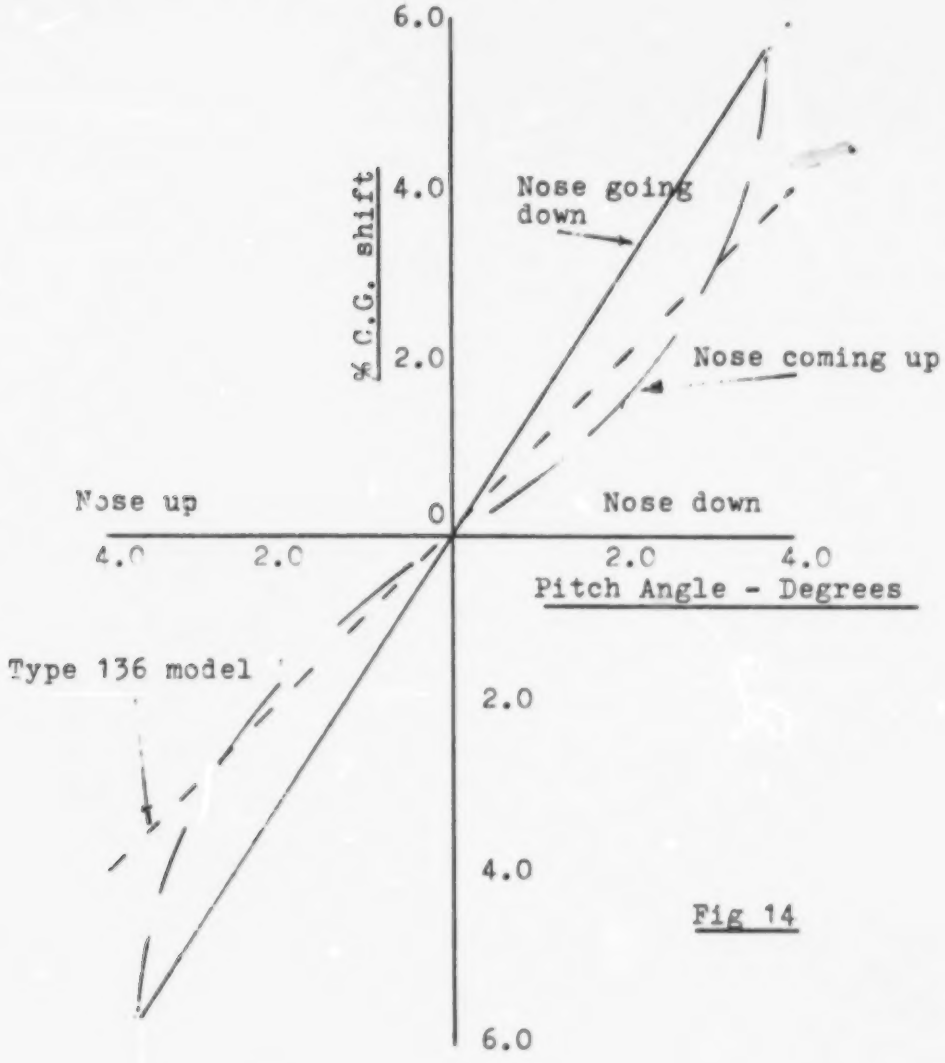


Fig 14

Type 140 Model with H.D.L. Segments
Weight = 43.5 kg
Fan R.P.M. = 2200

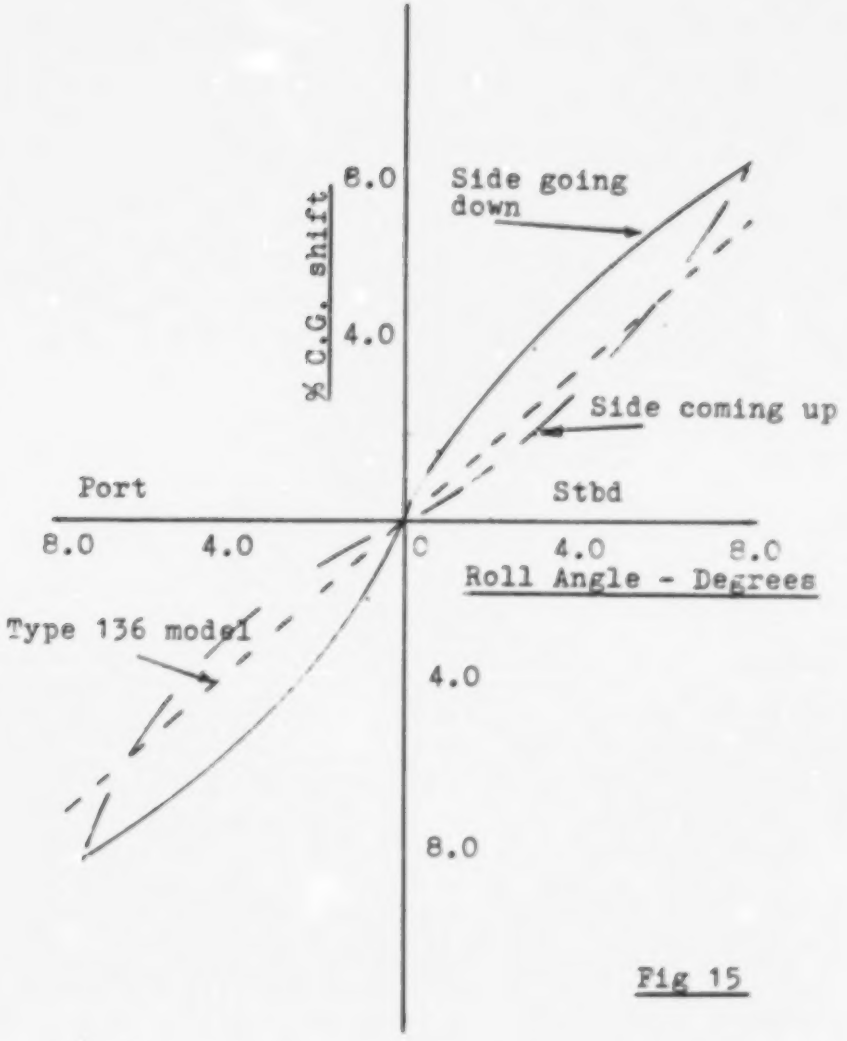


Fig 15

Model Type 140 - Modified Hybrid System
Weight = 43.5 kg
Fan R.P.M. = 2200

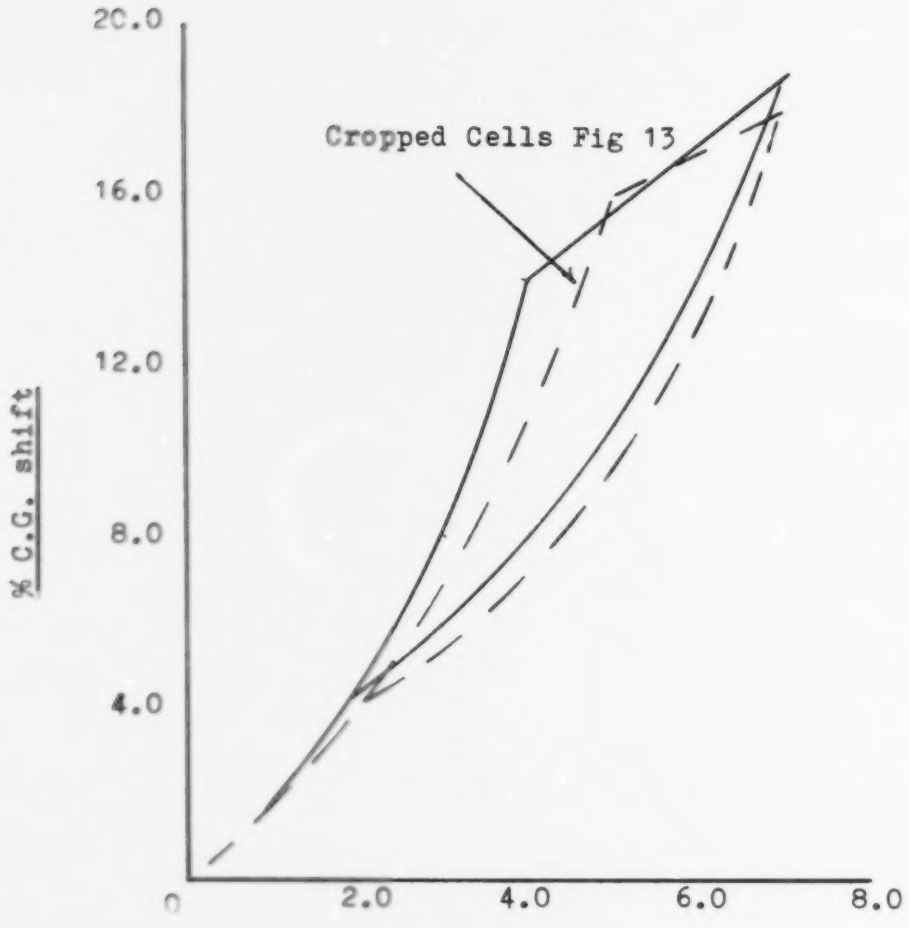


Fig 16

Type 140 Model - Modified Hybrid System
Weight = 43.5 kg
Fan R.P.M. = 2200

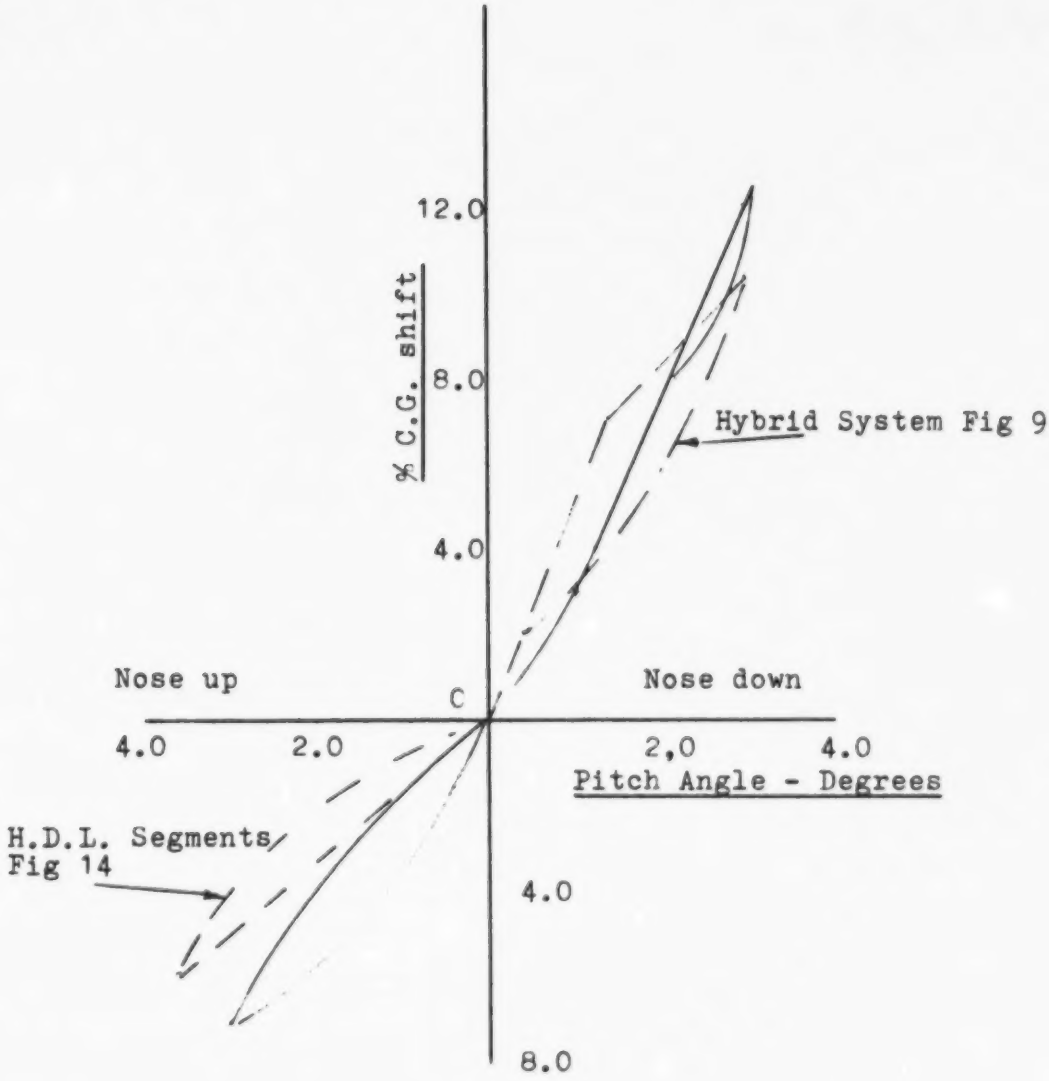
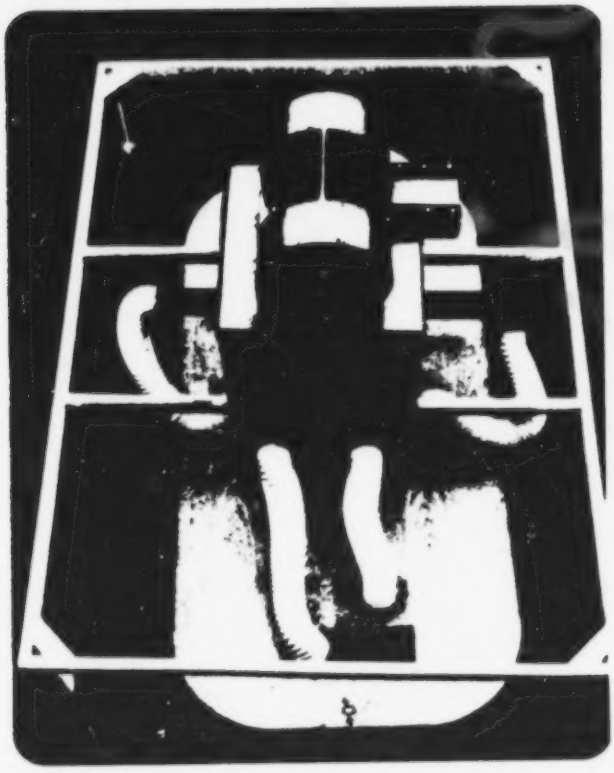


Fig 17



Test configuration for hard surface trials

Model in the towing tank

Fig 18

HYBRID SYSTEM

OVER WATER TESTS -

MODEL WEIGHT = 43.5 kgs

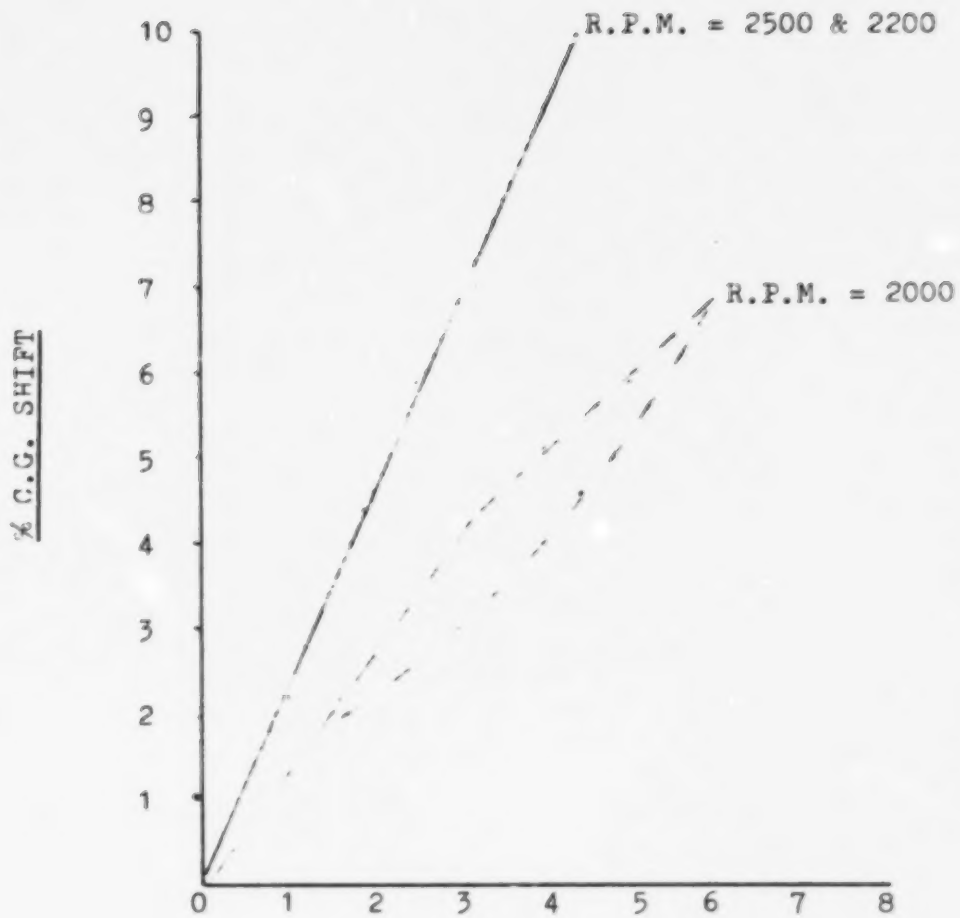


Fig 19

HYBRID SYSTEM

OVER WATER TESTS

MODEL WEIGHT = 43.5 kgs

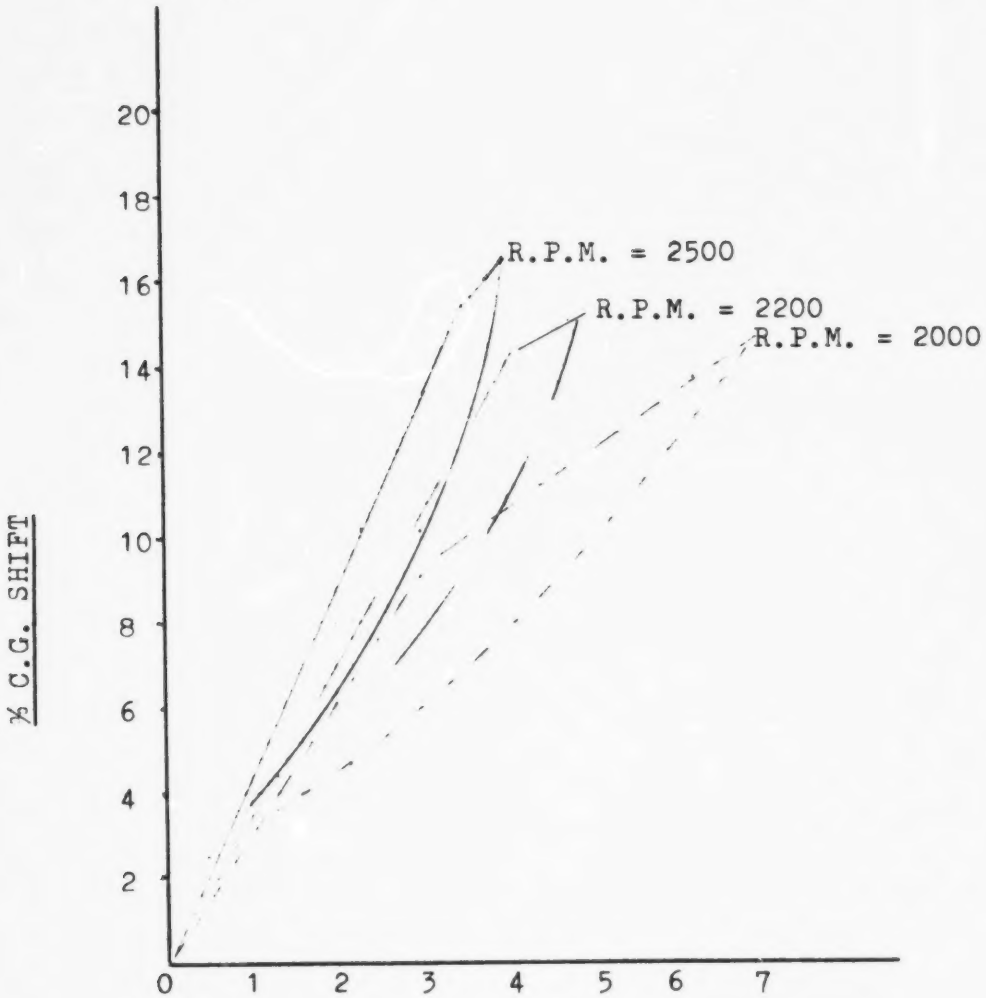


Fig 20

HYBRID SYSTEM

OVER WATER TESTS

MODEL WEIGHT = 50 kg

FAN SPEED = 2500 R.P.M.

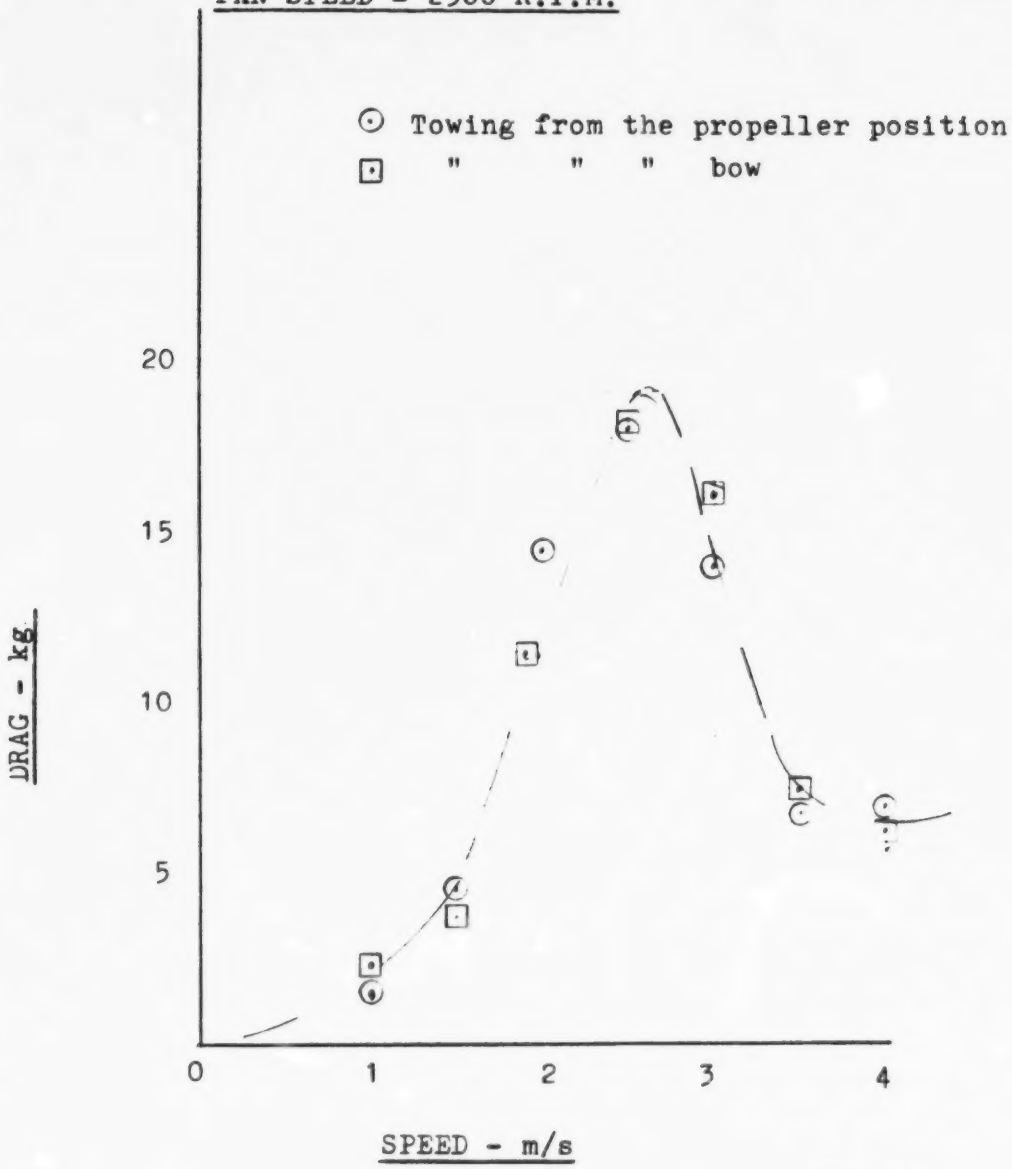


Fig 21

HYBRID SYSTEM

OVER WATER TESTS

FAN SPEED = 2500 R.P.M.

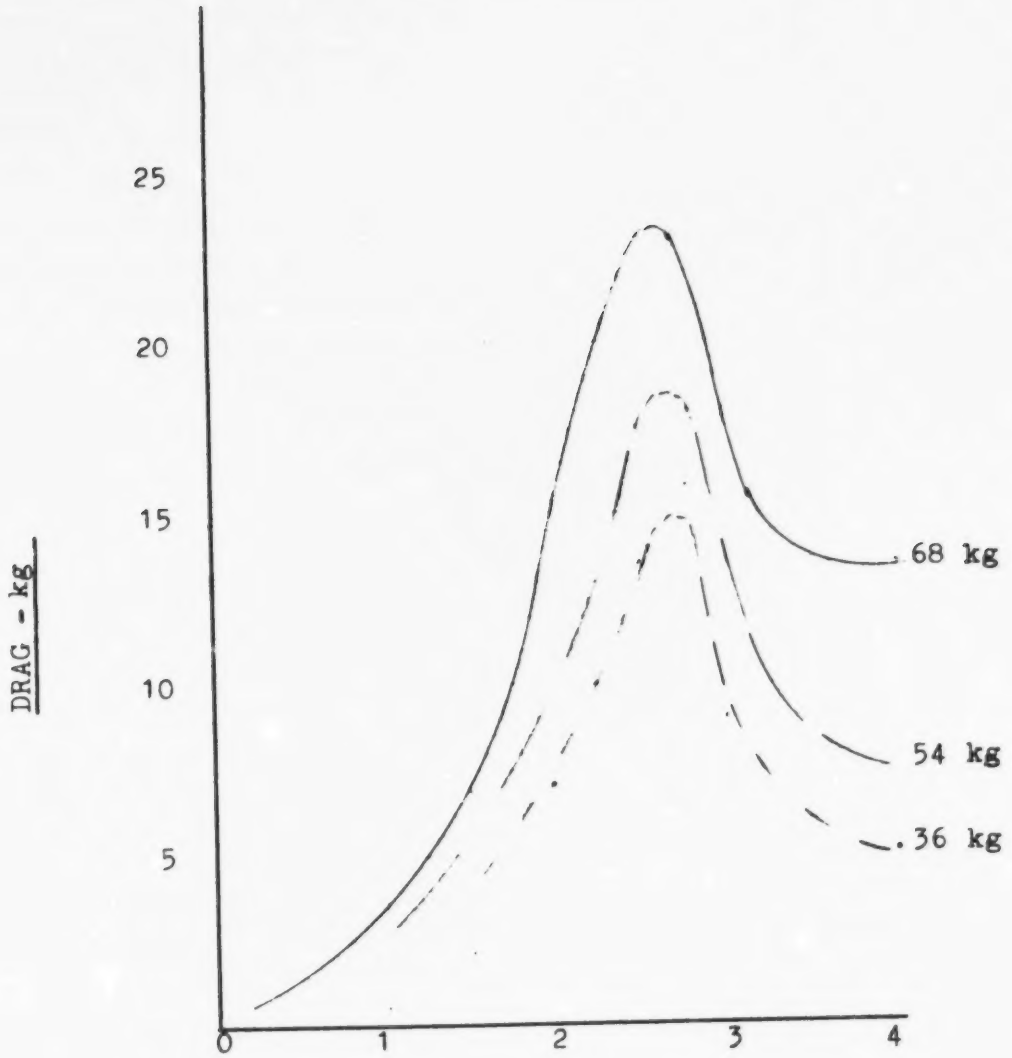


Fig 22

HYBRID SYSTEM

OVER WATER TESTS

MODEL WEIGHT = 36 kg

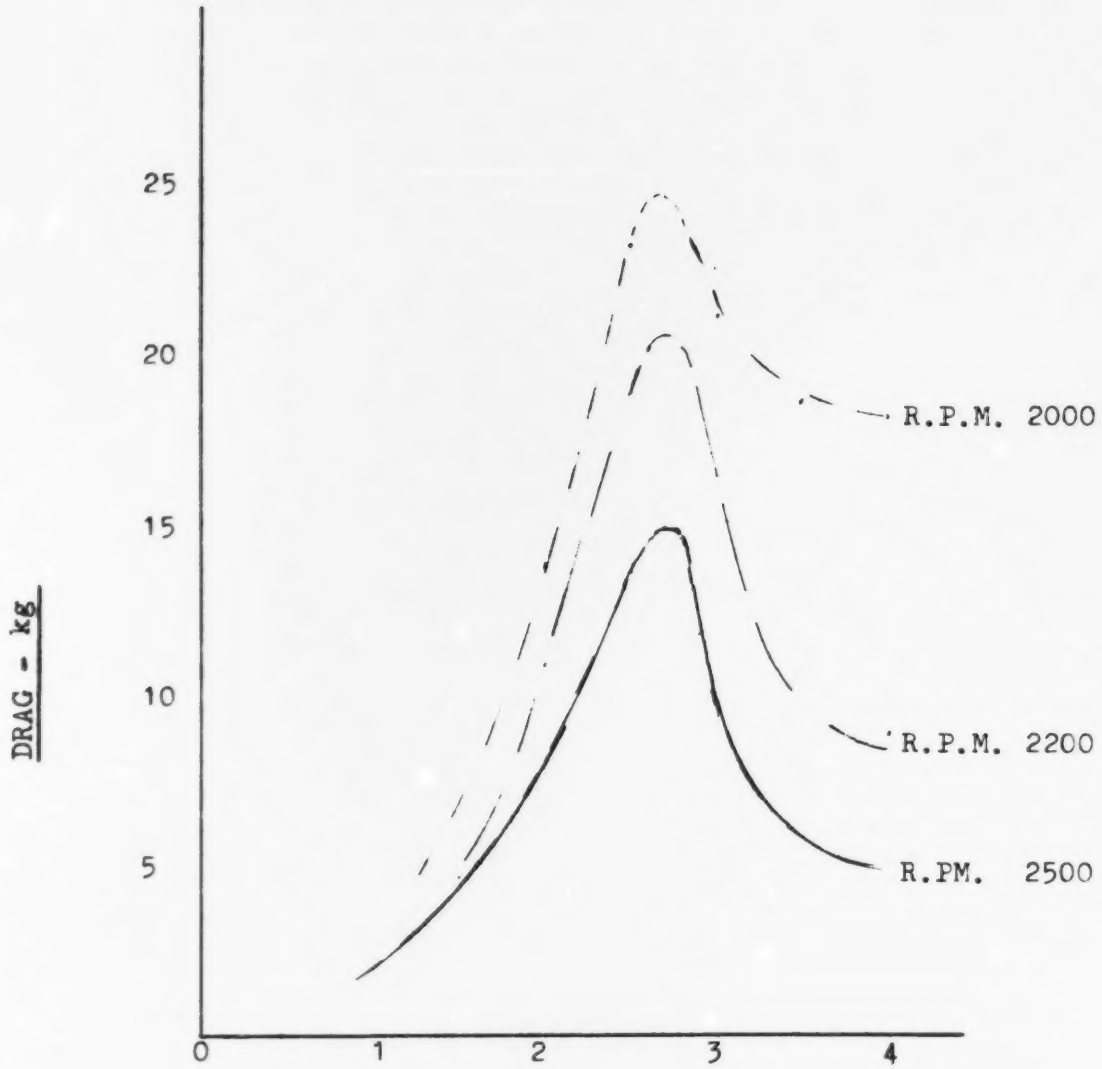


Fig 23

Over Water Drag of the H.D.L. Segments

Effect of Rear Apron

Model weight = 43.5 kg

C.G. = 0%

Fan speed = 2200 R.P.M.

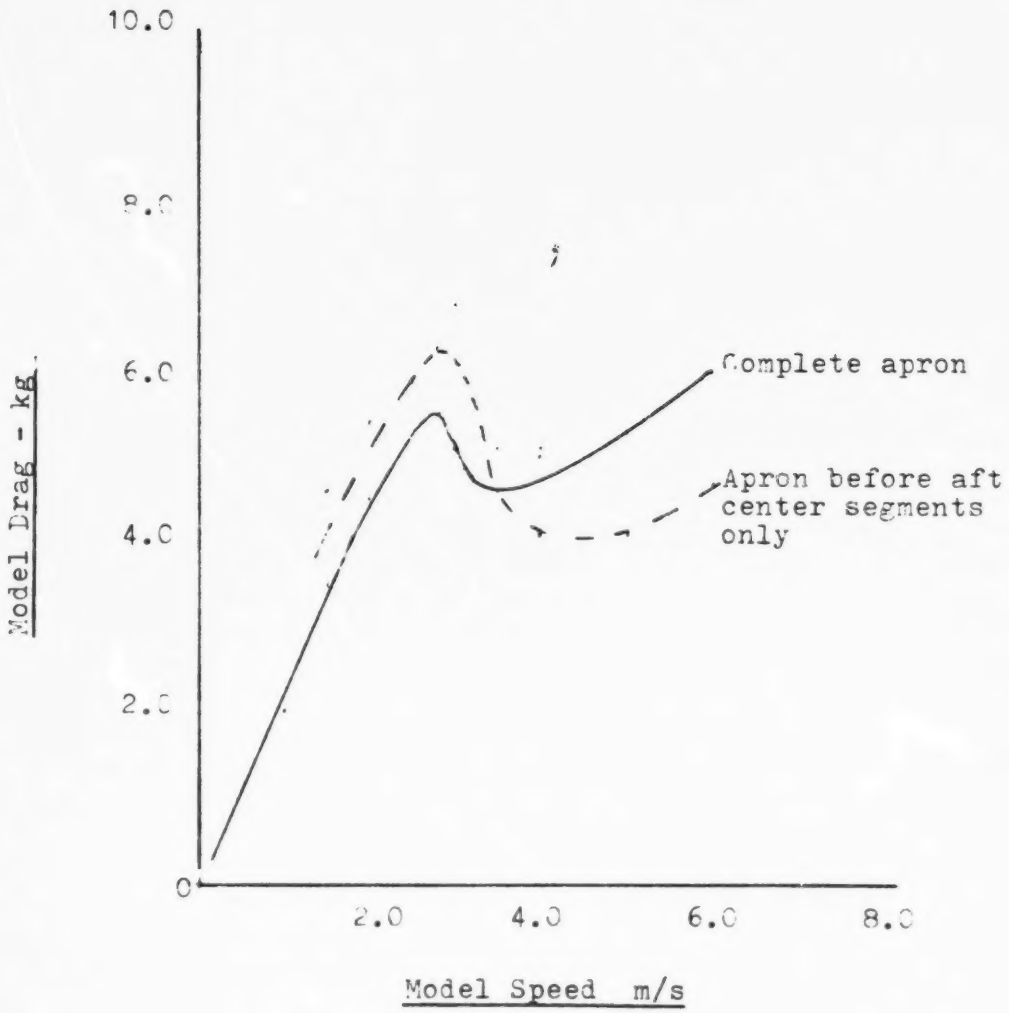


Fig 24

OVER WATER DRAG OF H.D.L. SEGMENTS

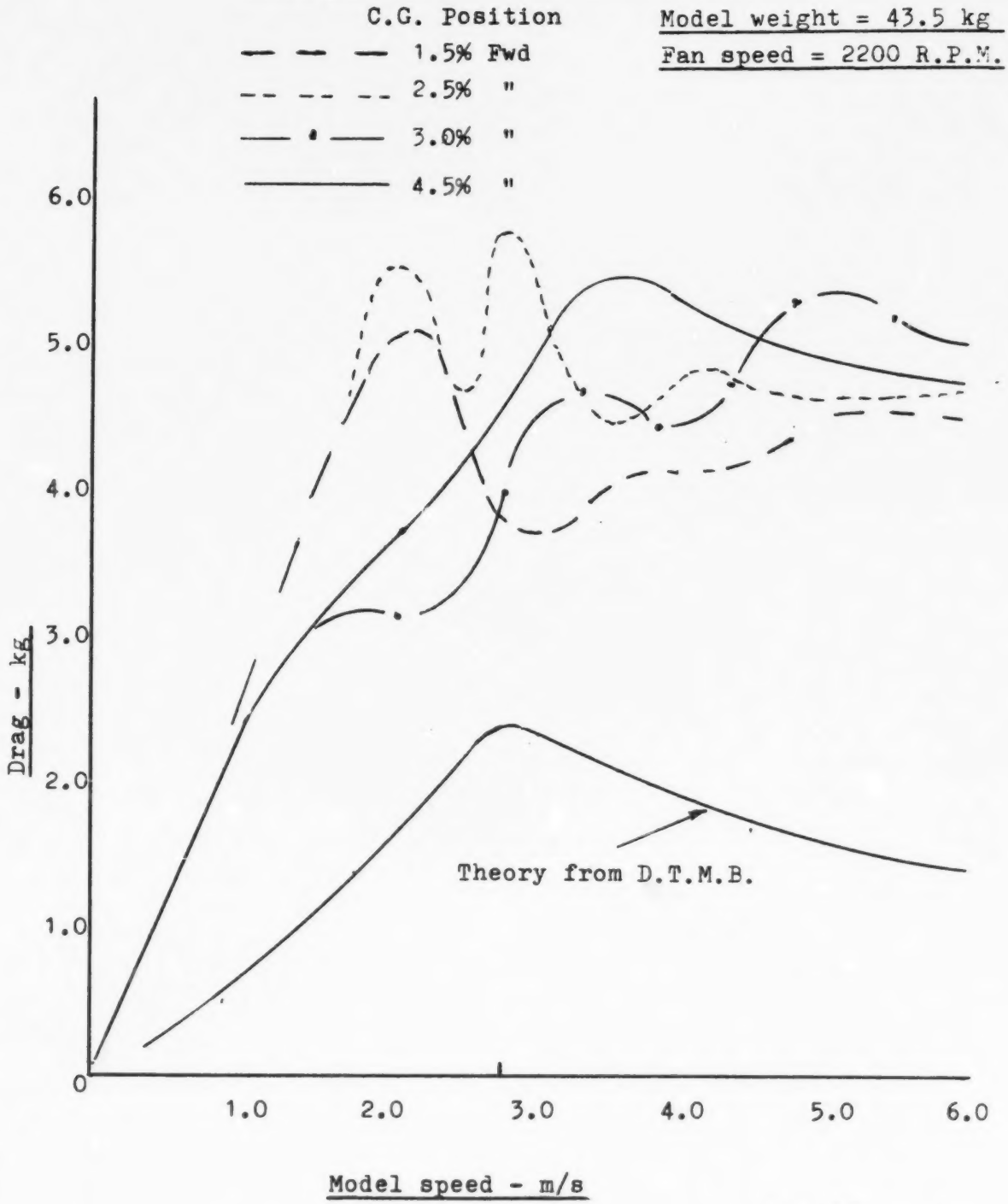


Fig 25

H.D.L. Segmented Skirt
Effect of Weight

Fan speed = 2200 R.PM.

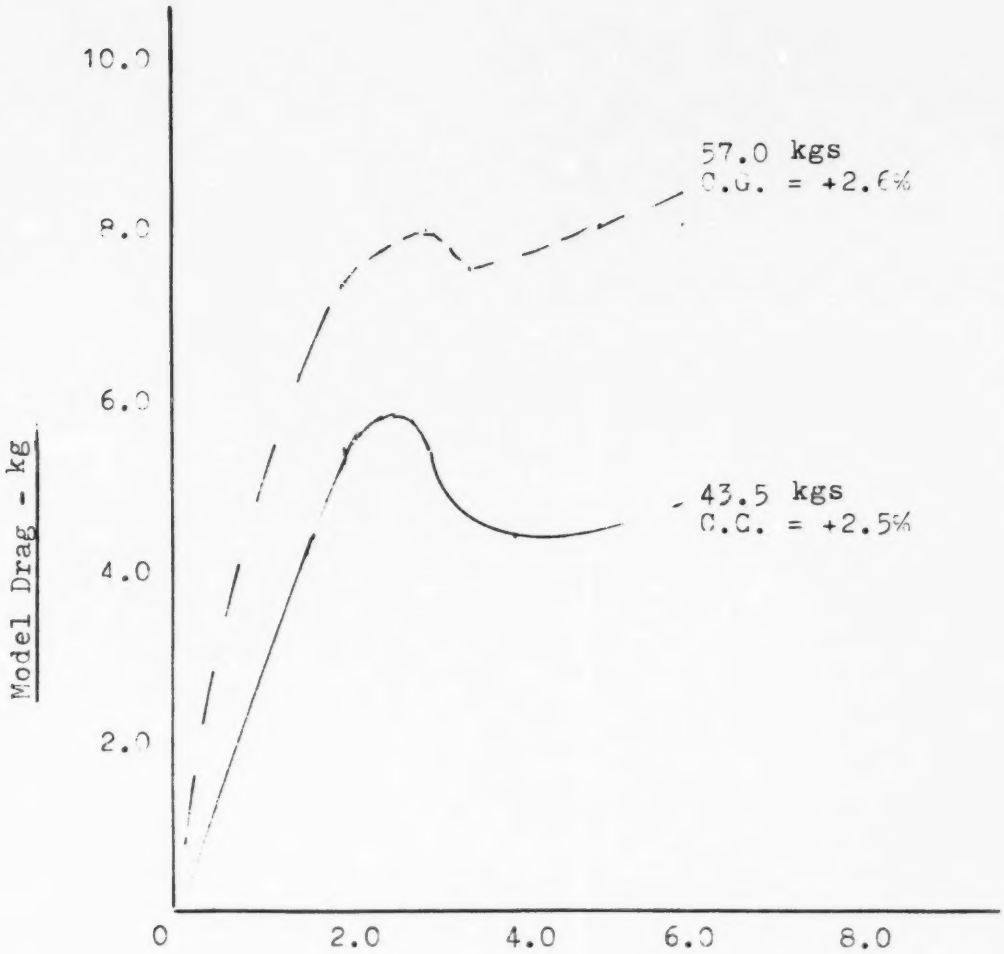


Fig 26

Modified Hybrid System
Effect of Weight & C.G. Position

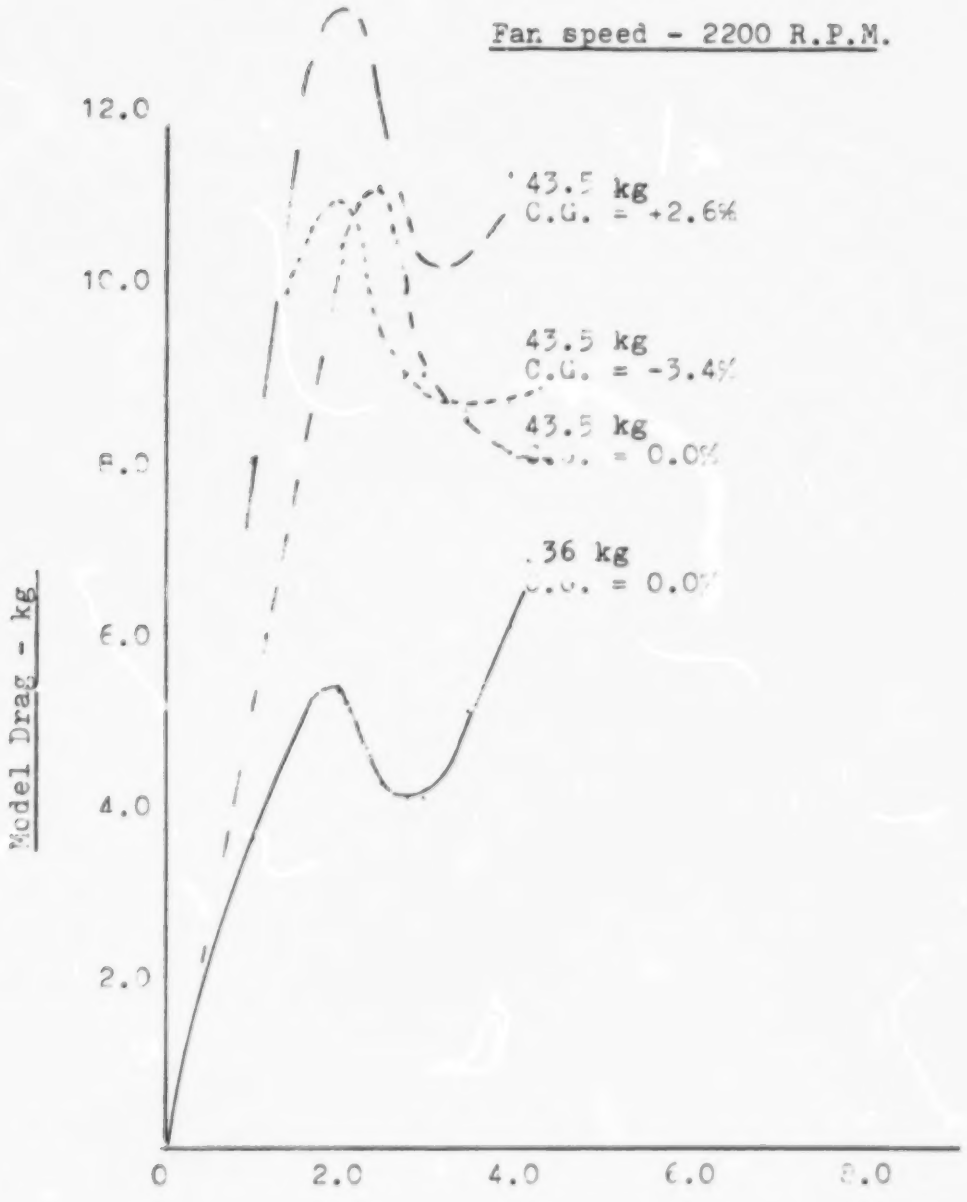


Fig 27

Modified Hybrid System
Effect of Fan Speed

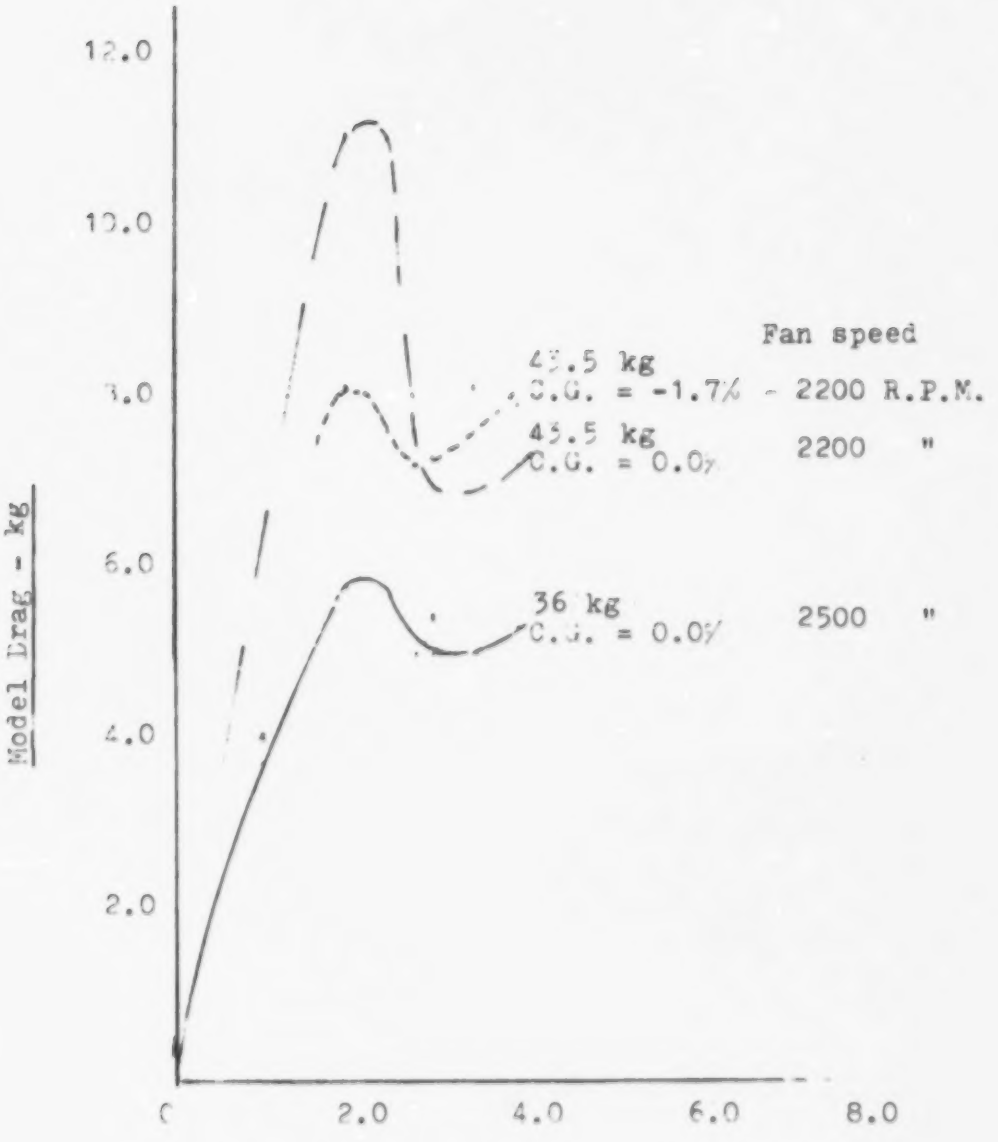


Fig 28

Over Water Drag of the Hybrid Cellular Skirt

C.G. = 0%

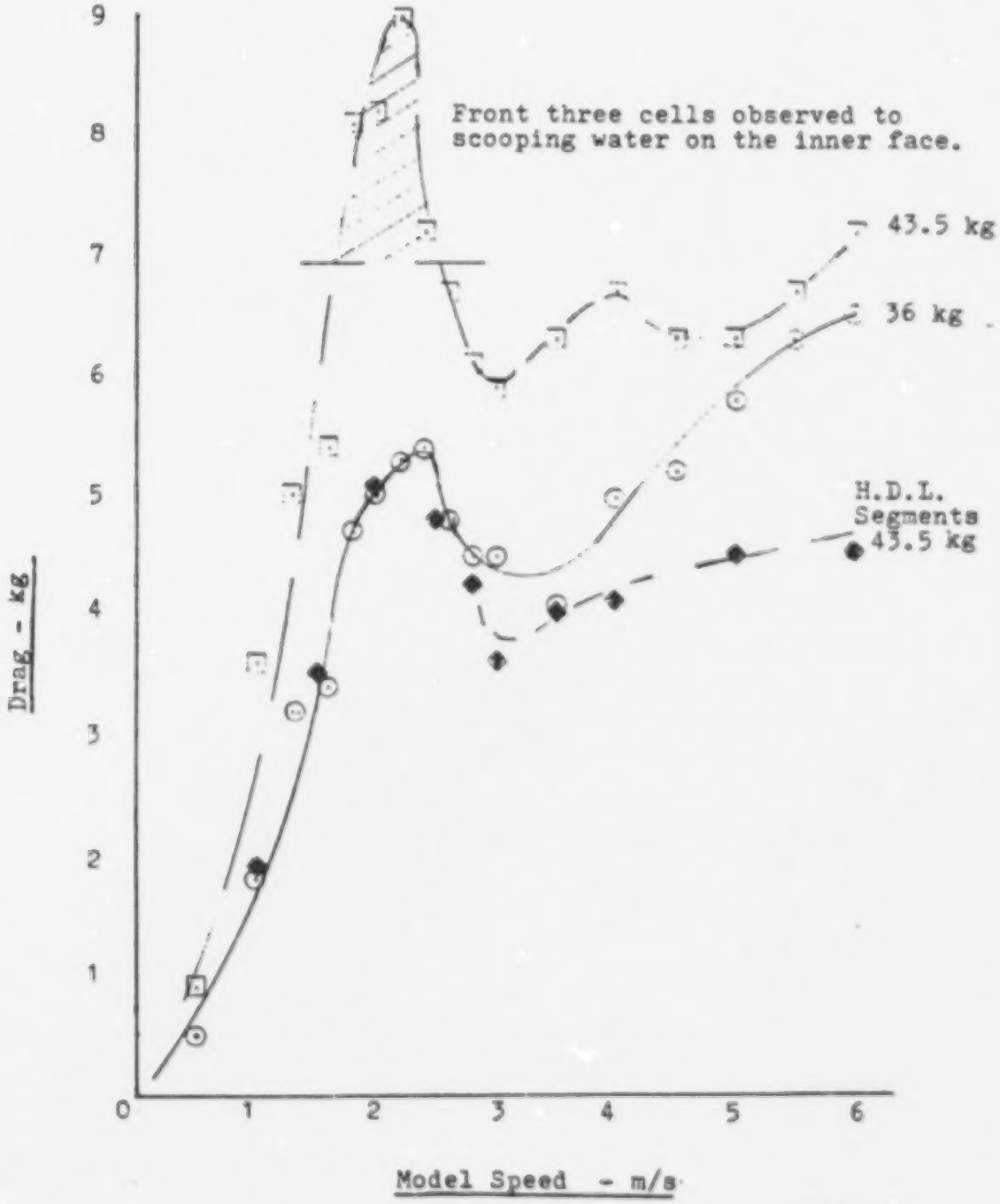


Fig 29

Effect of Water Depth
on Maximum Drag

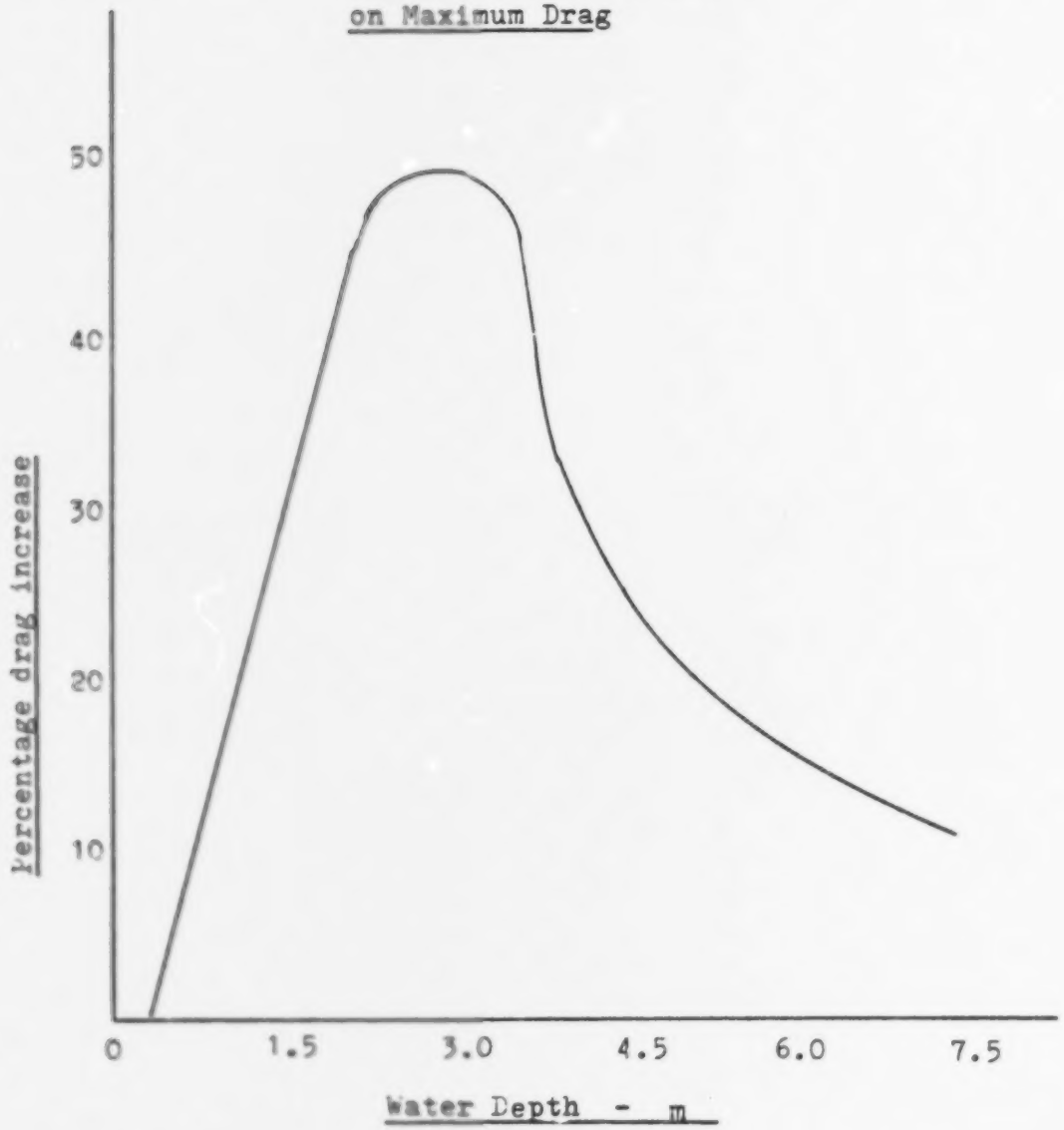


Fig 30

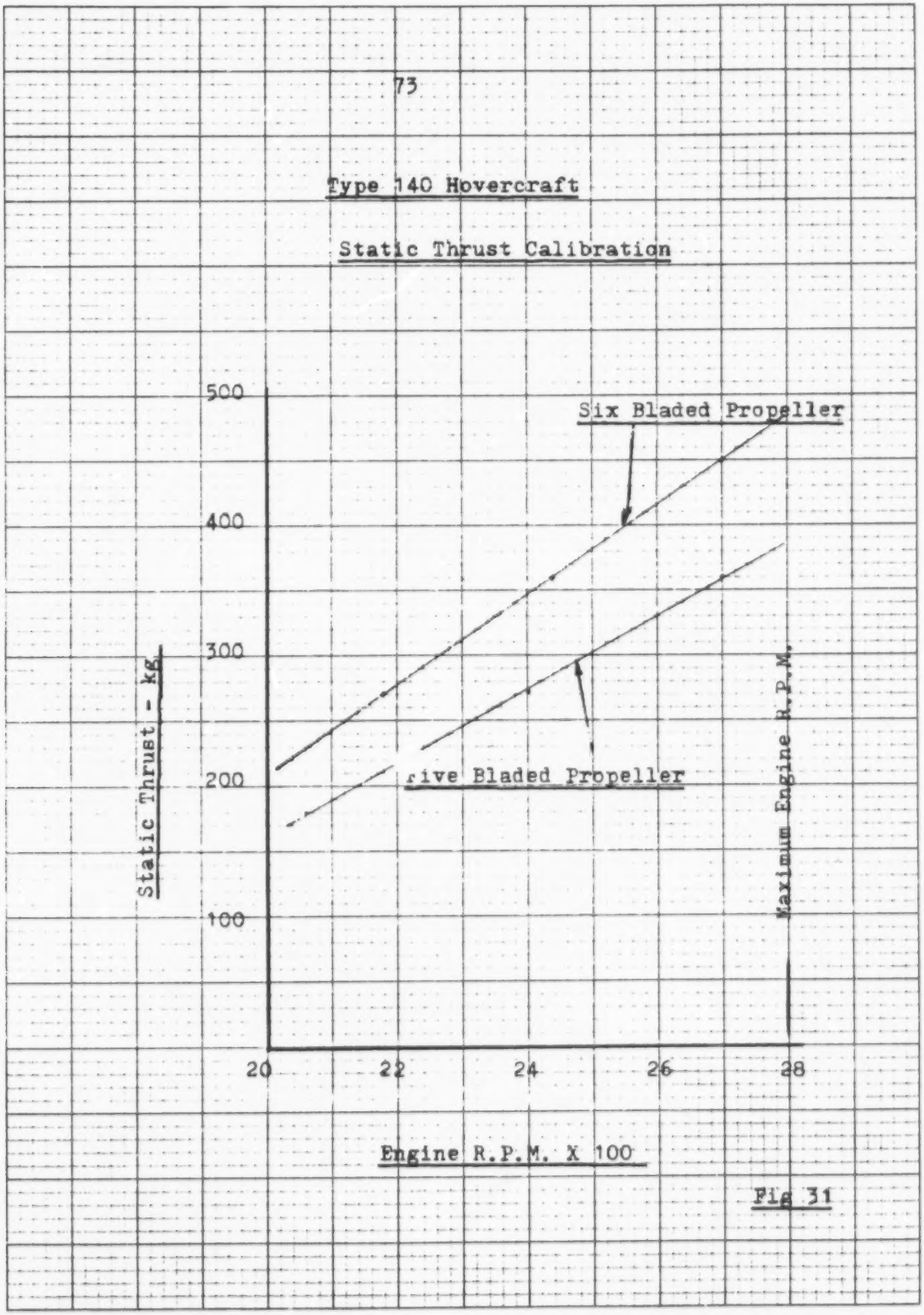


Fig 31

10 Squares to the Inch

Type 140 Estimated Calm Water Drag

Vehicle Weight = 5400 kg

Water Depth = 3.7 m

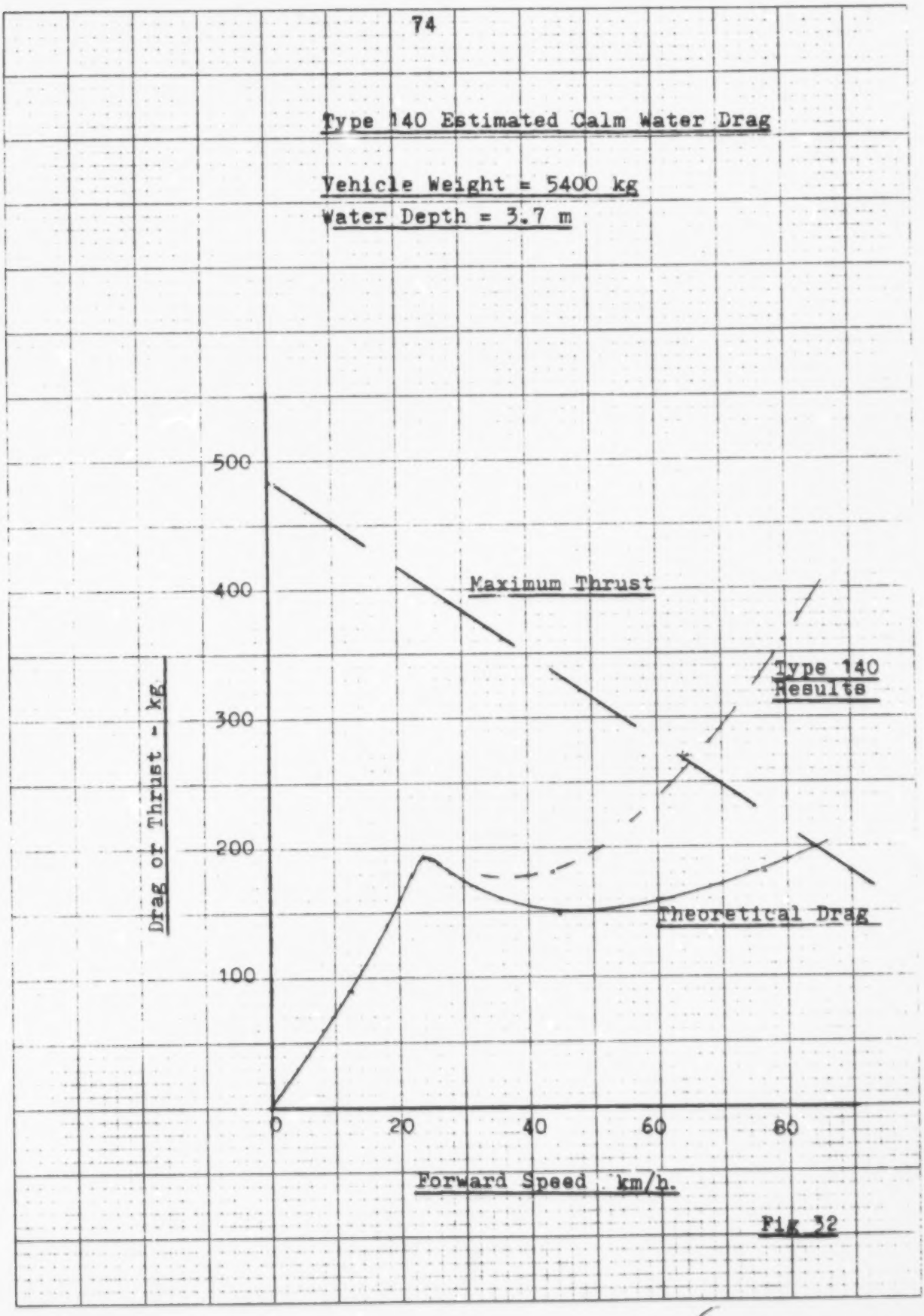
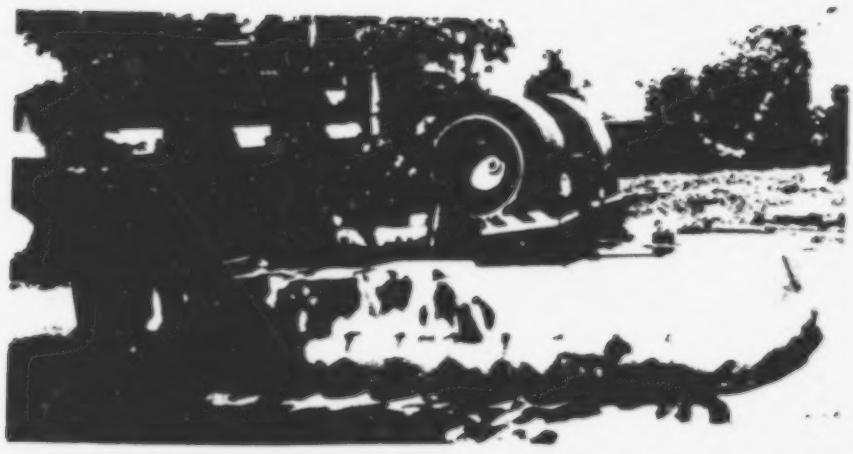
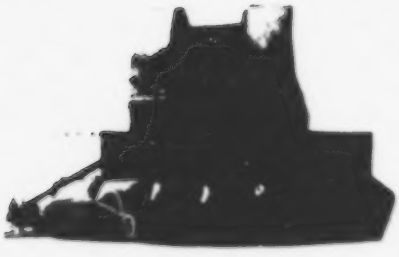


Fig 32

10 Squares to the Inch



FRONT SIDE



FULL FRONT

ABOVE DECK

REAR SIDE

Fig 33

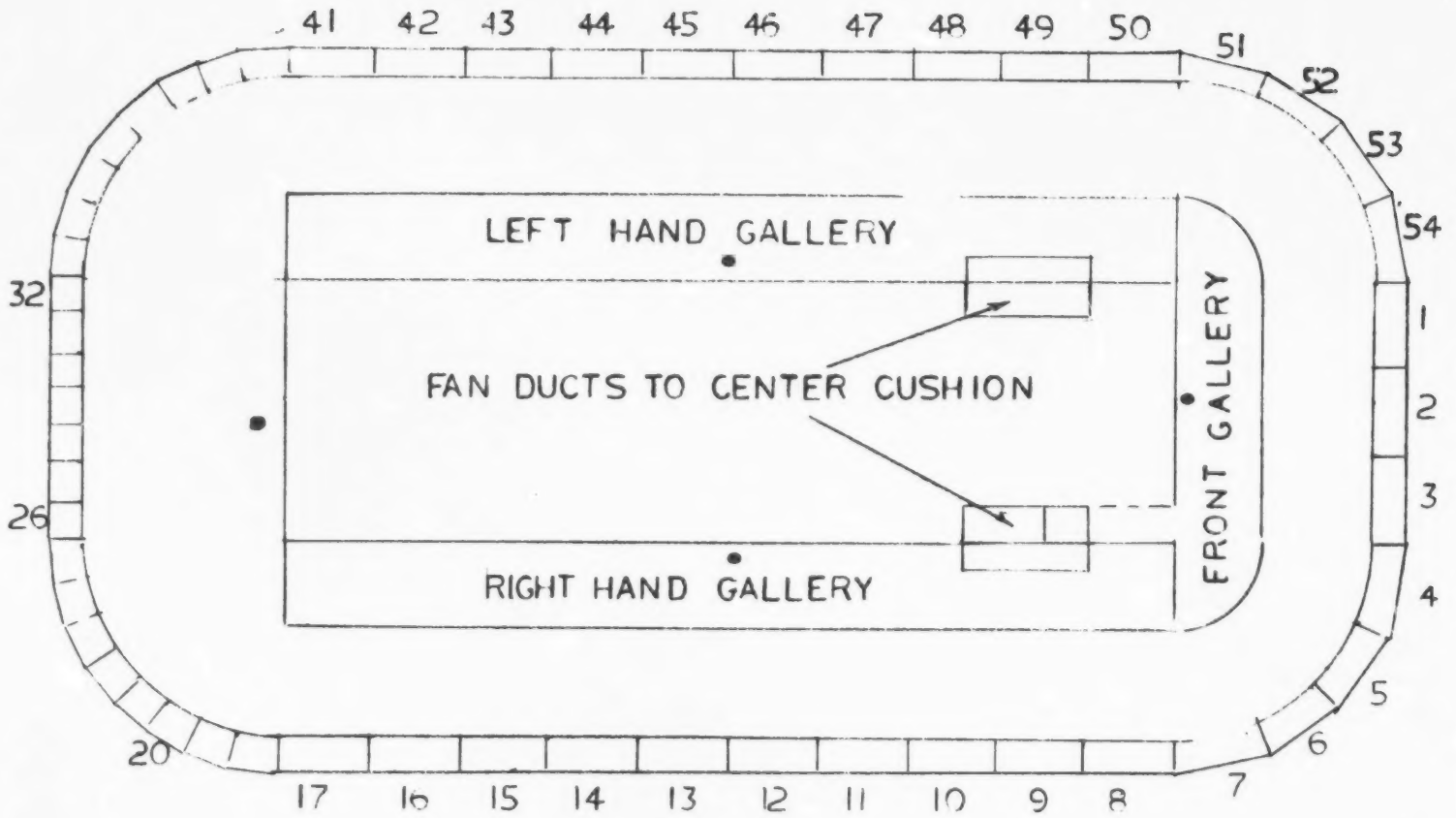
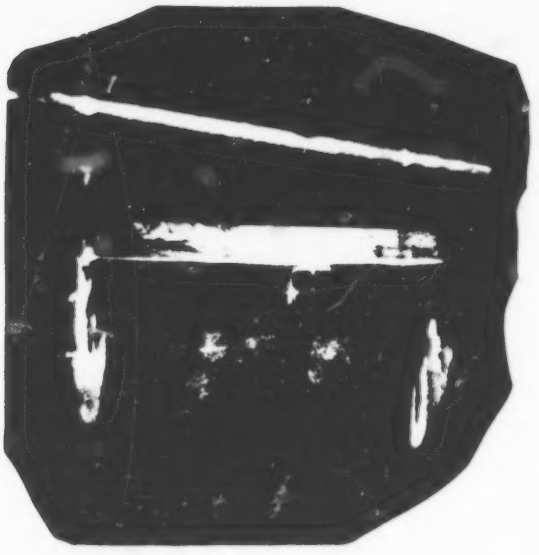
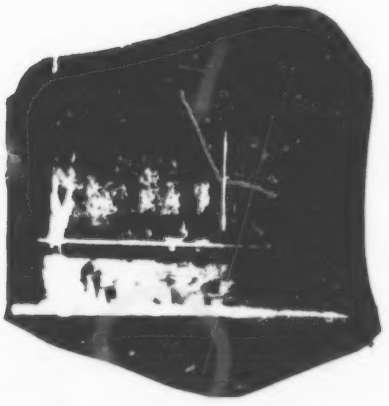


FIG 34

•PRESSURE TAP POSITIONS



LEFT HAND GALLERY ENTRY



RIGHT HAND GALLERY ENTRY

Fig 35

Modified Hybrid System
Model No. 2

Fan Pressure = 1.30
Cushion "

Model Weight = 538 kg

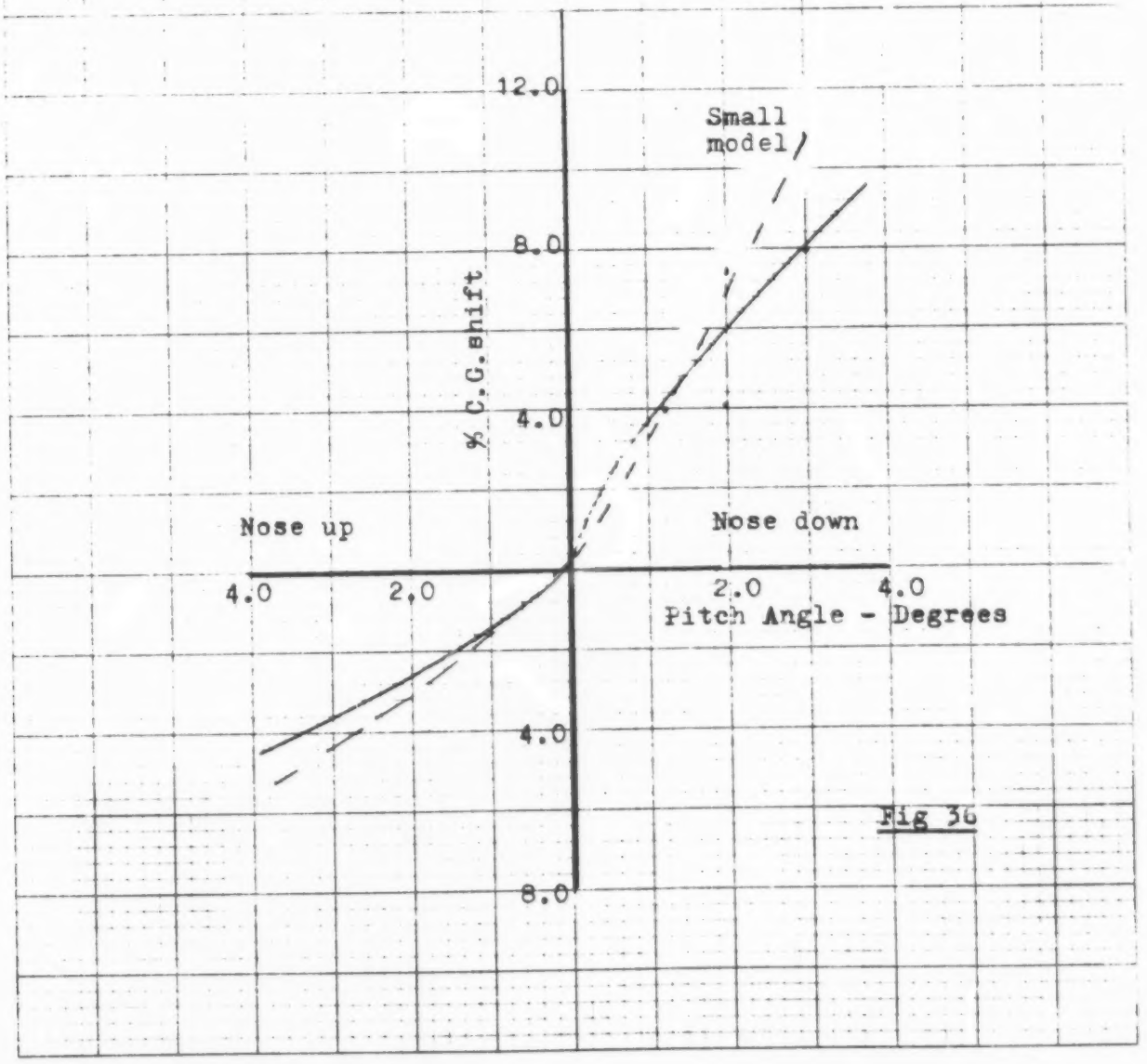


Fig 36

Modified Hybrid System

Model No. 2

Fan Pressure Cushion = 1.30

Model Weight = 538 kg

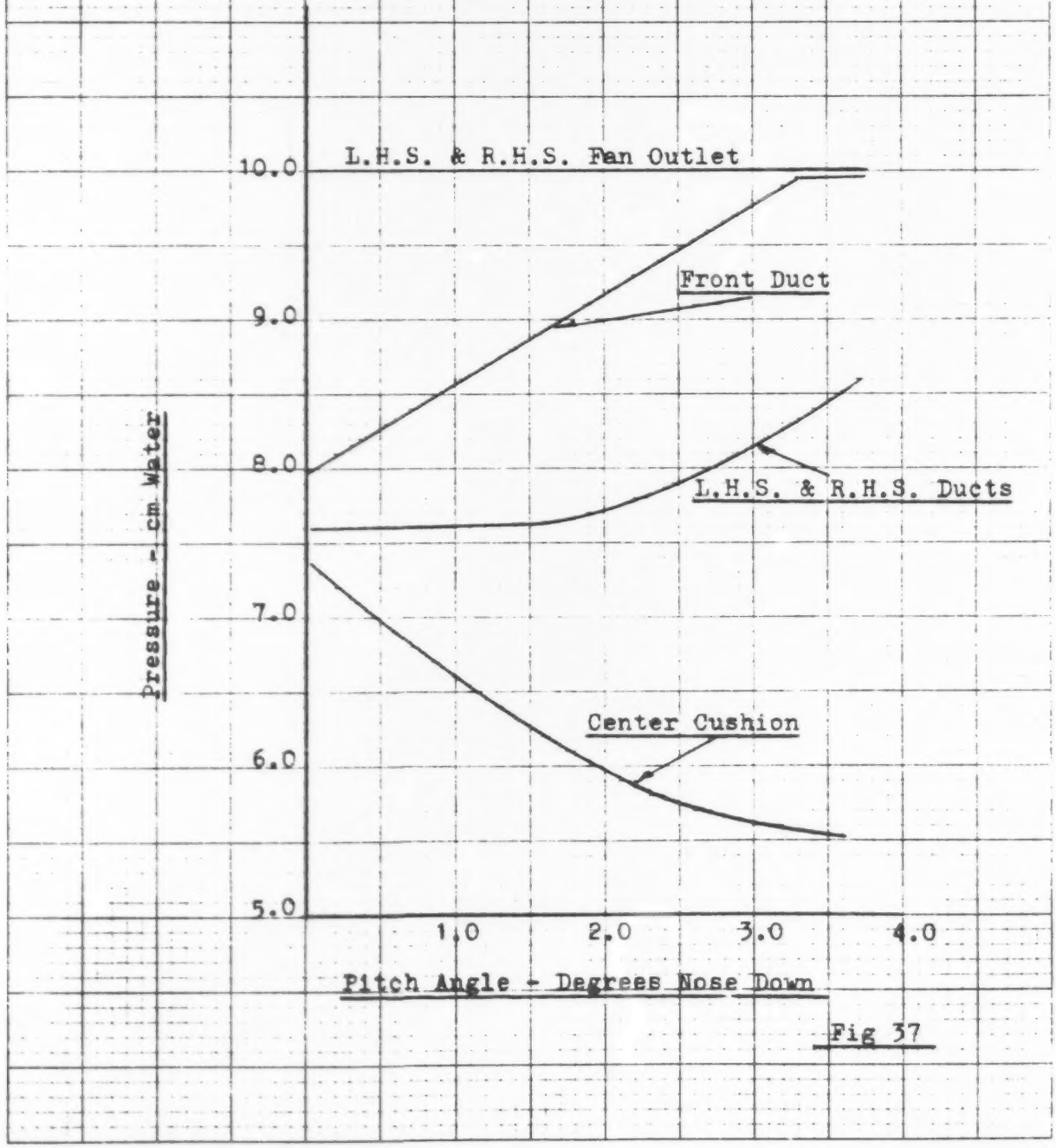


Fig 37

Modified Hybrid System
Model No 2

Fan Pressure = 1.30
Cushion

Model Weight = 538 kg

Pitch Angle = 3.0 Degrees

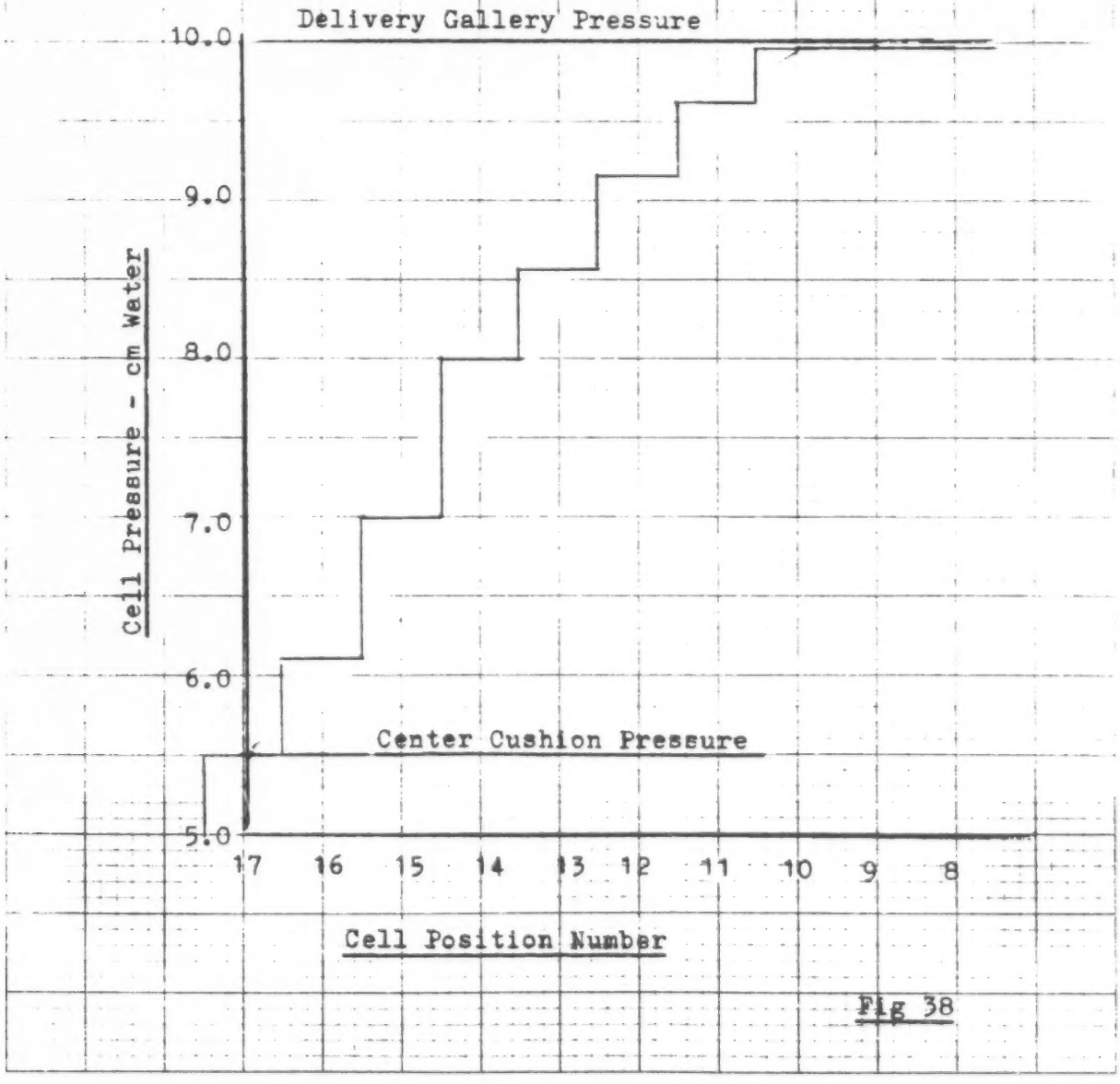


Fig 38

10 Squares to the Inch

B1

Modified Hybrid System
Model No. 2

Fan Pressure = 1.30 Cushion

Model Weight = 538 kg

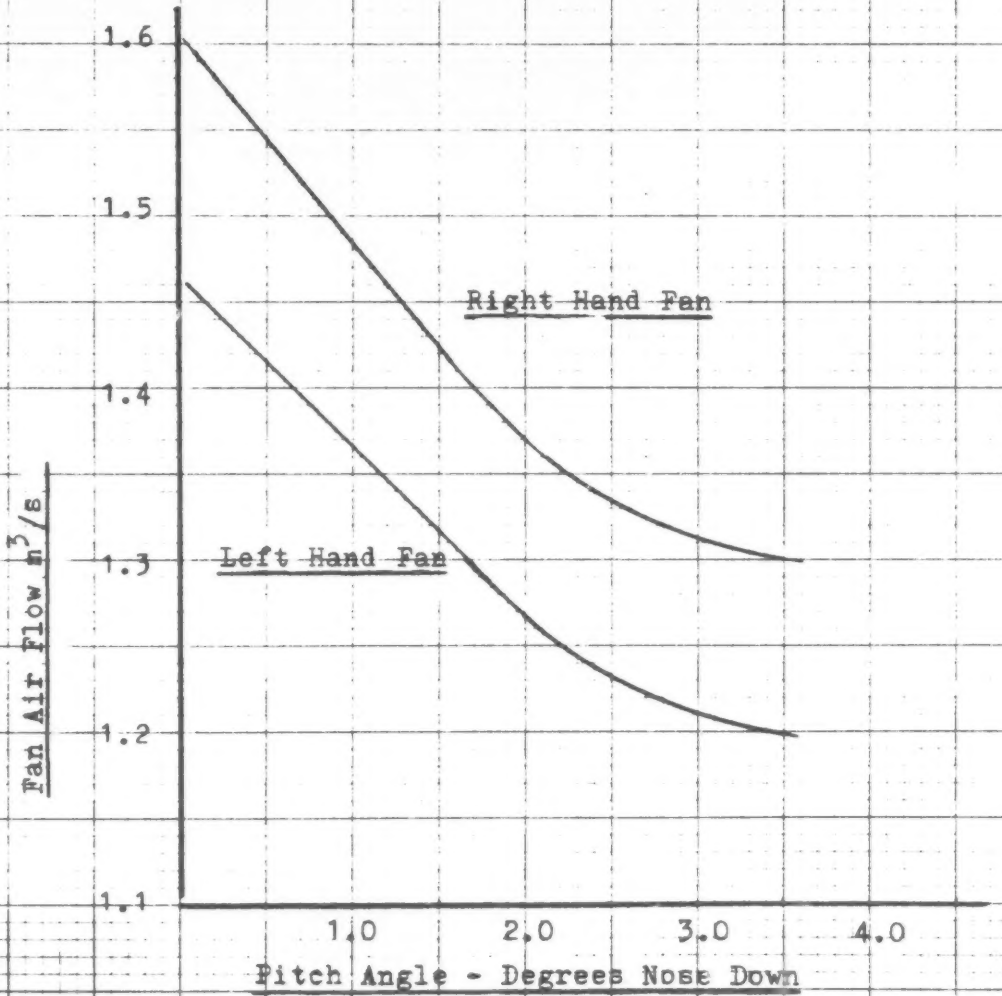


Fig 39

10 Squares to the Inch

B2

Modified Hybrid System

Model No. 2

Fan Pressure Cushion = 1.30

Model Weight = 538 kg

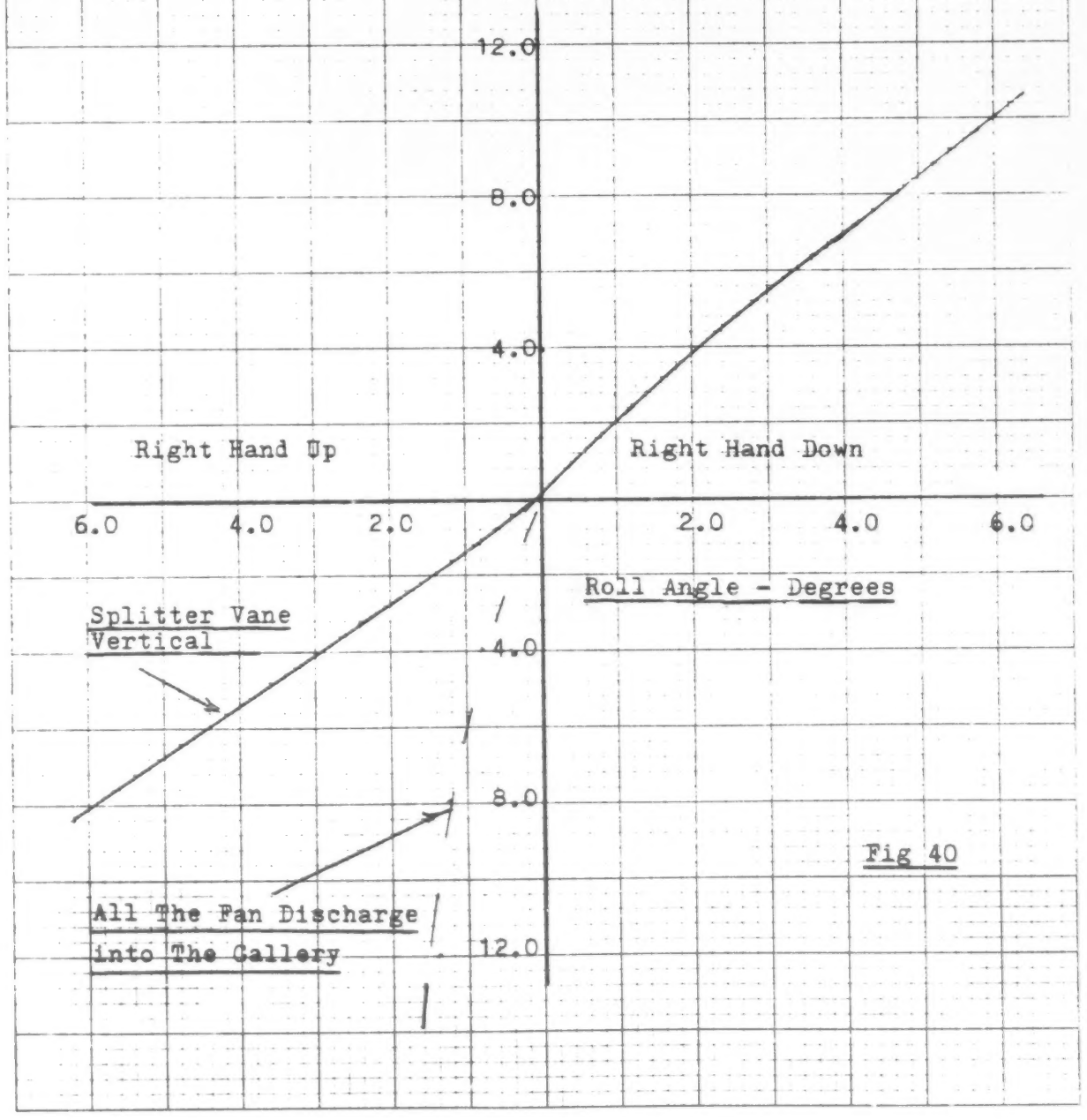


Fig 40

10 Squares to the Inch

Modified Hybrid System
Model No. 2

Fan Pressure = 1.30
Cushion
Model Weight = 538 kg

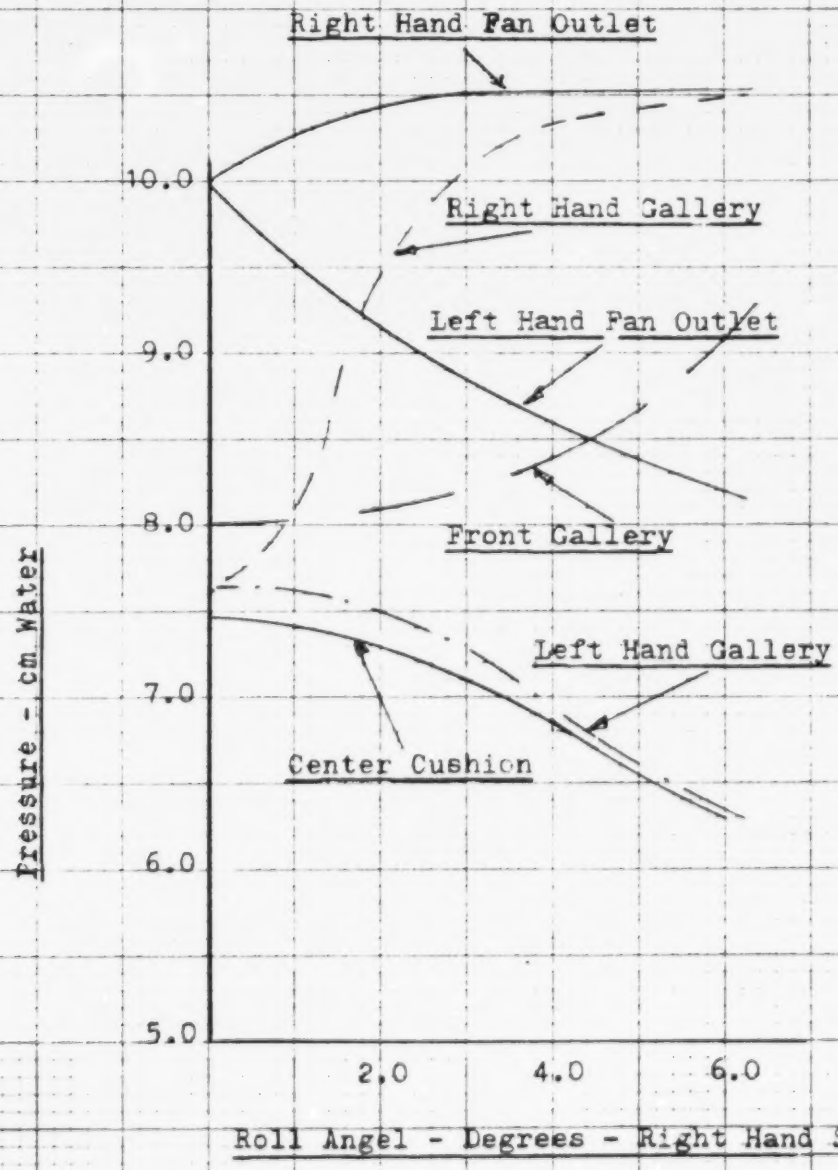


Fig 41

Modified Hybrid System
Model No. 2

Fan Pressure = 1.30
Cushion
Model Weight = 538 kg
Roll Angle = 5.0 Degrees

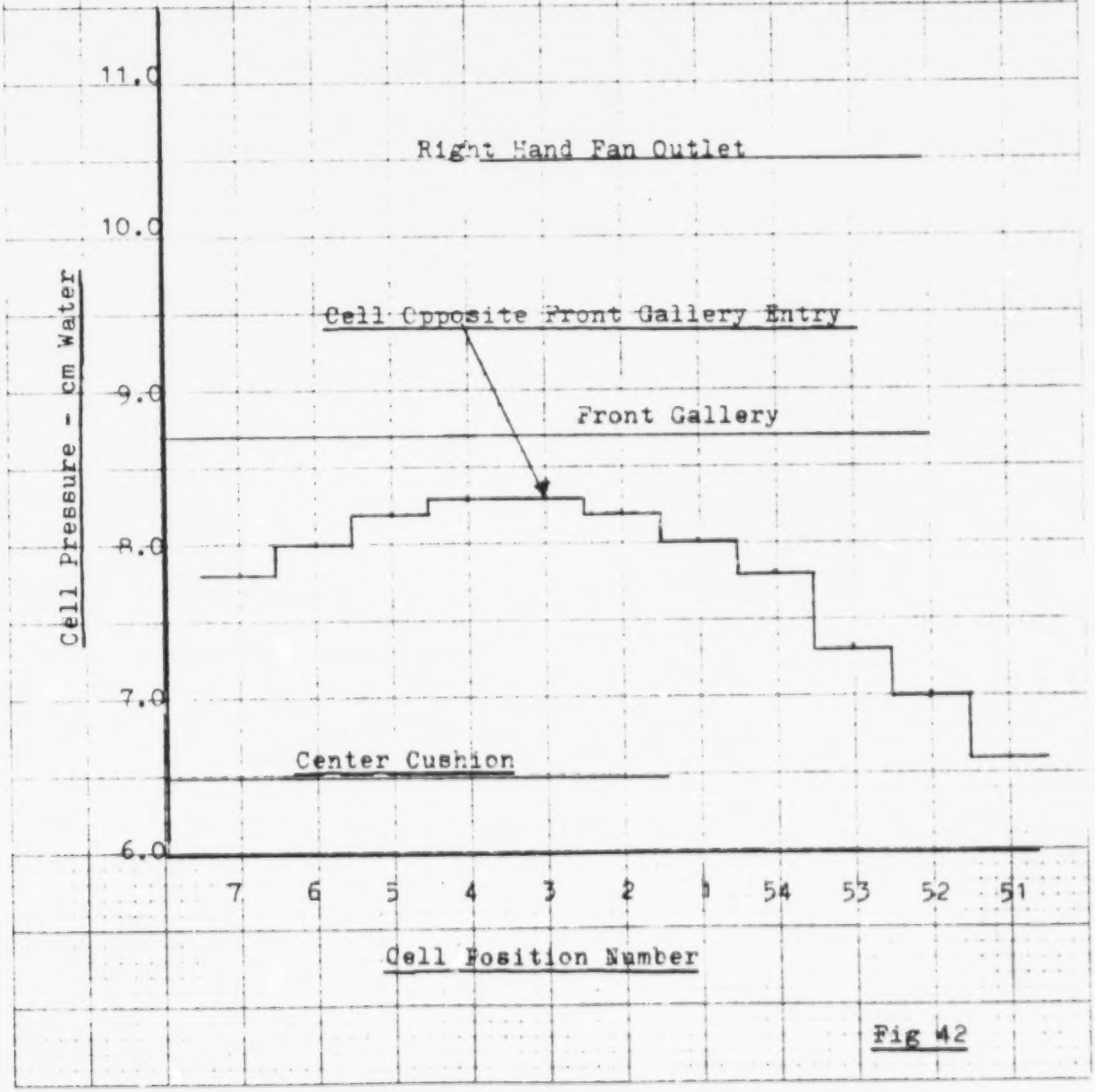


Fig 42

Modified Hybrid System
Model No. 2

Fan Pressure / Cushion = 1.30
Model Weight = 538 kg

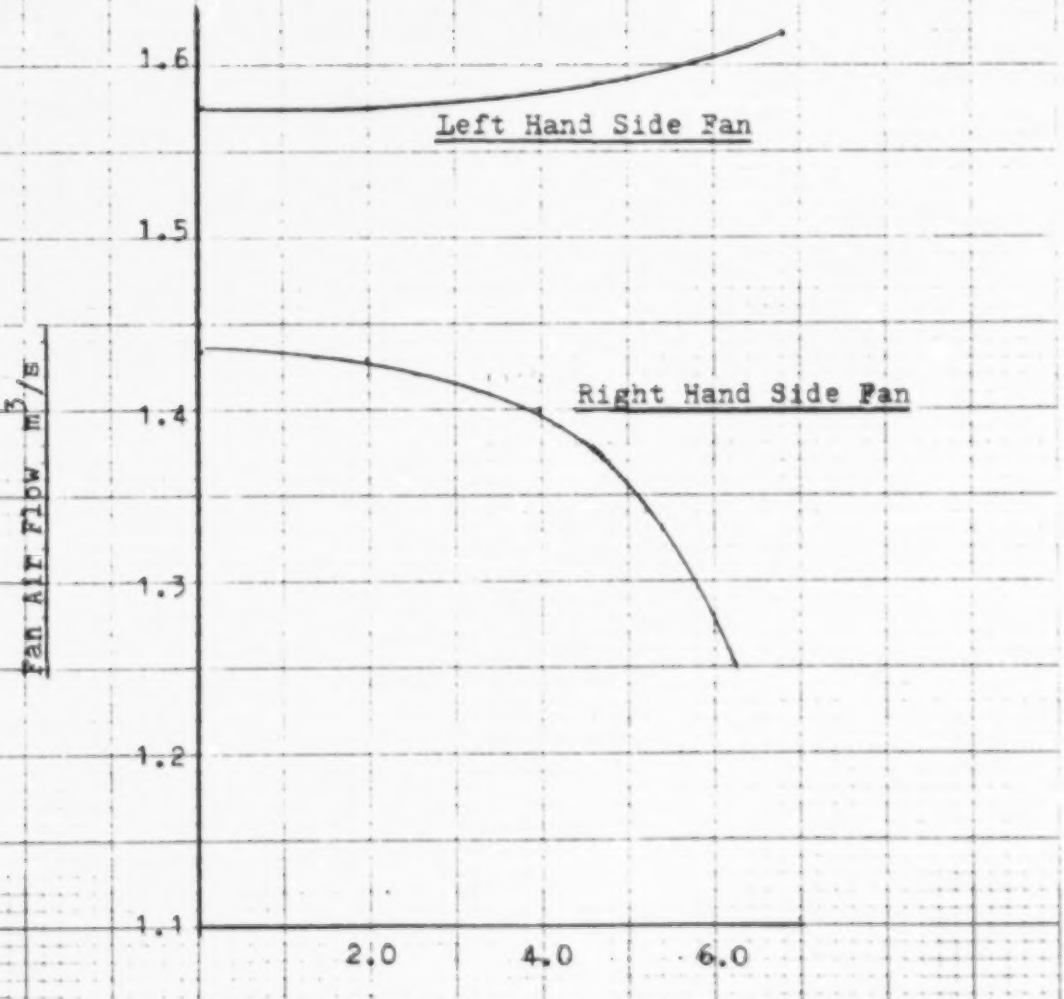


Fig 43

10 Squares to the Inch

Modified Hybrid System
Model No. 2

Fan Pressure = 1.3
Cushion "

Model Weight = 665 kg

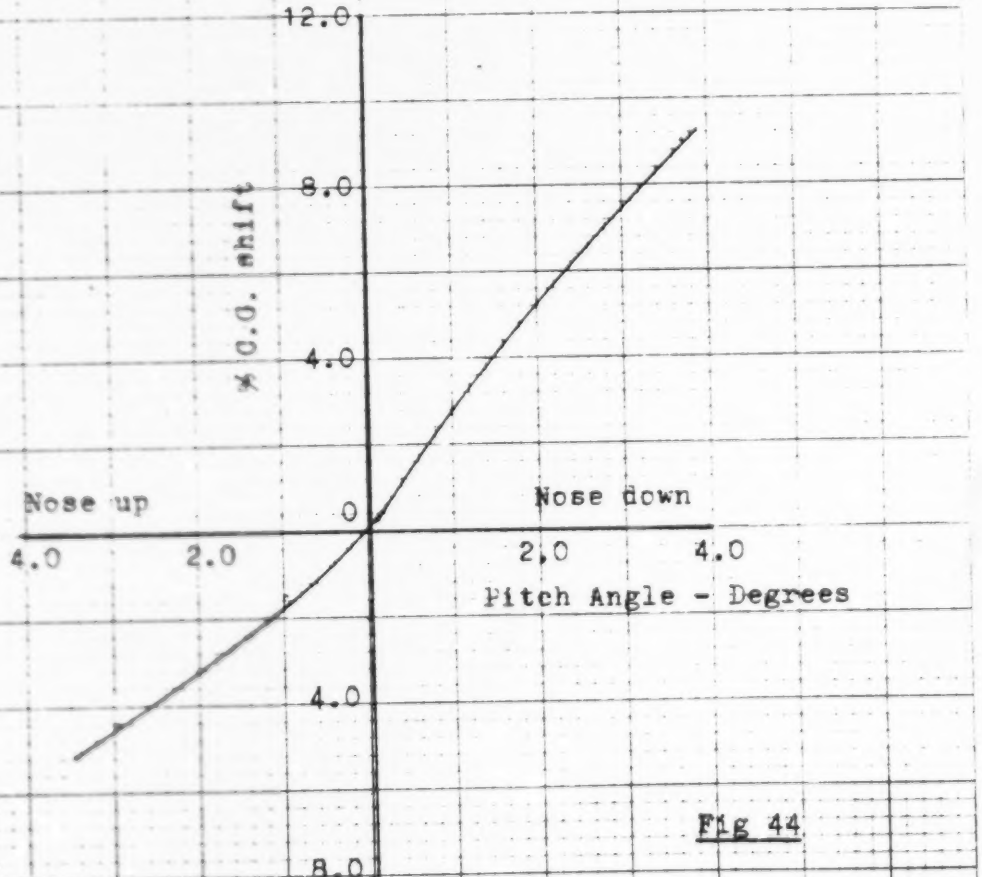


Fig 44

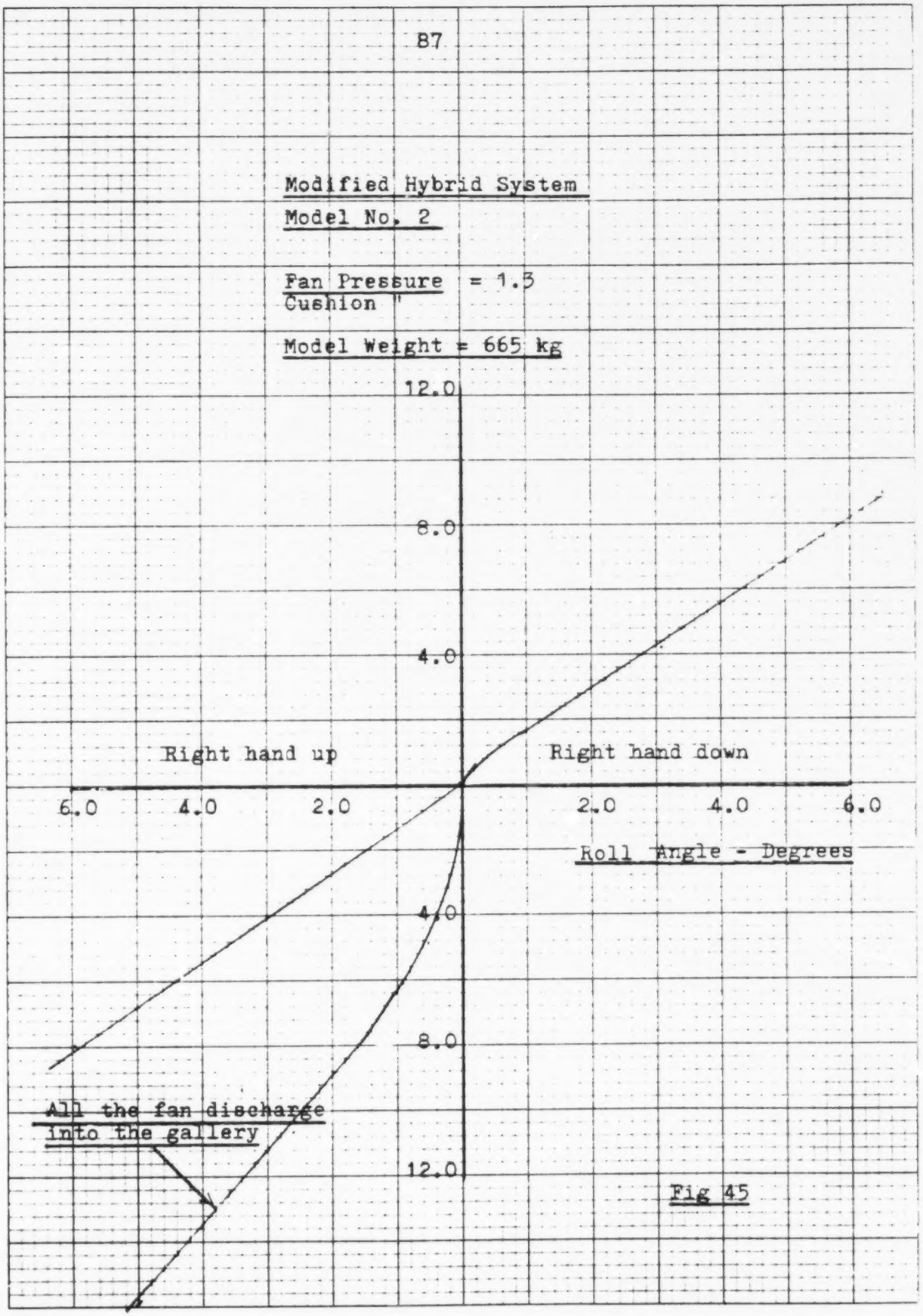


Fig 45

10 Squares to the Inch

Modified Hybrid System

Model No 2

Fan Pressure = 1.3
Cushion "

Model Weight = 538 kg

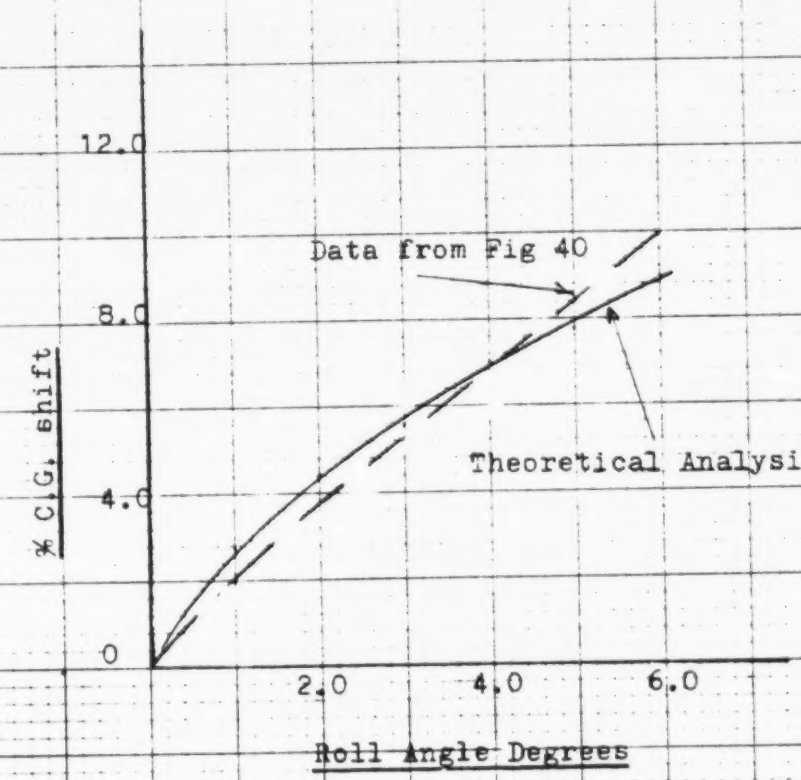


Fig 46

POOR
QUALITY
ORIGINAL